OWYHEE DAM
Owyhee River
Nyssa Vicinity
Malheur County
Oregon

HAER NO. OR-17

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23-NYS.V,
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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Department of the Interior
Western Regional Office
450 Golden Gate Avenue
P.O. Box 36063
San Francisco, California 94102

HISTORIC AMERICAN ENGINEERING RECORD **HAER No. OR-17**
OWYHEE DAM
MALHEUR COUNTY, OREGON

HAER
ORE
23-NYS.V,
1-

Location:	Owyhee River, eleven miles southwest of Adrian, Malheur County, Oregon
Quads:	Owyhee Dam, Oregon
UTM:	Zone 11 A: E - 480420; N - 4832050 B: E - 480730; N - 4832050 C: E - 480730; N - 4832810 D: E - 480420; N - 4832810
Construction Dates:	1928-1932
Present Owner:	U.S. Department of the Interior, Bureau of Reclamation
Present Use:	Storage dam for irrigation and generation of hydroelectricity
Significance:	Owyhee Dam is a 417-foot-high, concrete thick-arch dam (or arch/gravity dam). At its completion in 1932, Owyhee was the tallest dam in the world, a short-lived distinction because it was superceded in 1936 with the completion of 726-foot high Hoover Dam. Owyhee Dam has engineering significance as the proving ground for construction techniques developed by Bureau of Reclamation engineers for use at Hoover Dam. Tests conducted on the cooling and shrinking of mass concrete as it cured at Owyhee Dam helped assure Bureau engineers that their techniques would work at Hoover Dam. Historic apparatus for monitoring those tests is still in place on the interior of Owyhee Dam. Owyhee also has engineering significance for its ancillary features. The ring gate on the Owyhee Dam spillway was the first ever built. It was the first dam in which a freight elevator was installed. The needle valves in the outlet works for Owyhee Dam, which make it possible to regulate the discharge of water under very high pressure, represent a late stage in the evolution of such valves by the Bureau of Reclamation. Upon its completion, Owyhee Dam began storing water for use by farmers on the Owyhee Project, one of the most important in the development of irrigated agriculture in Oregon.
Historians:	Fredric L. Quivik, Architectural Historian, and Amy Slaton, Historian, Renewable Technologies, Inc., Butte, MT
Date:	February 1991

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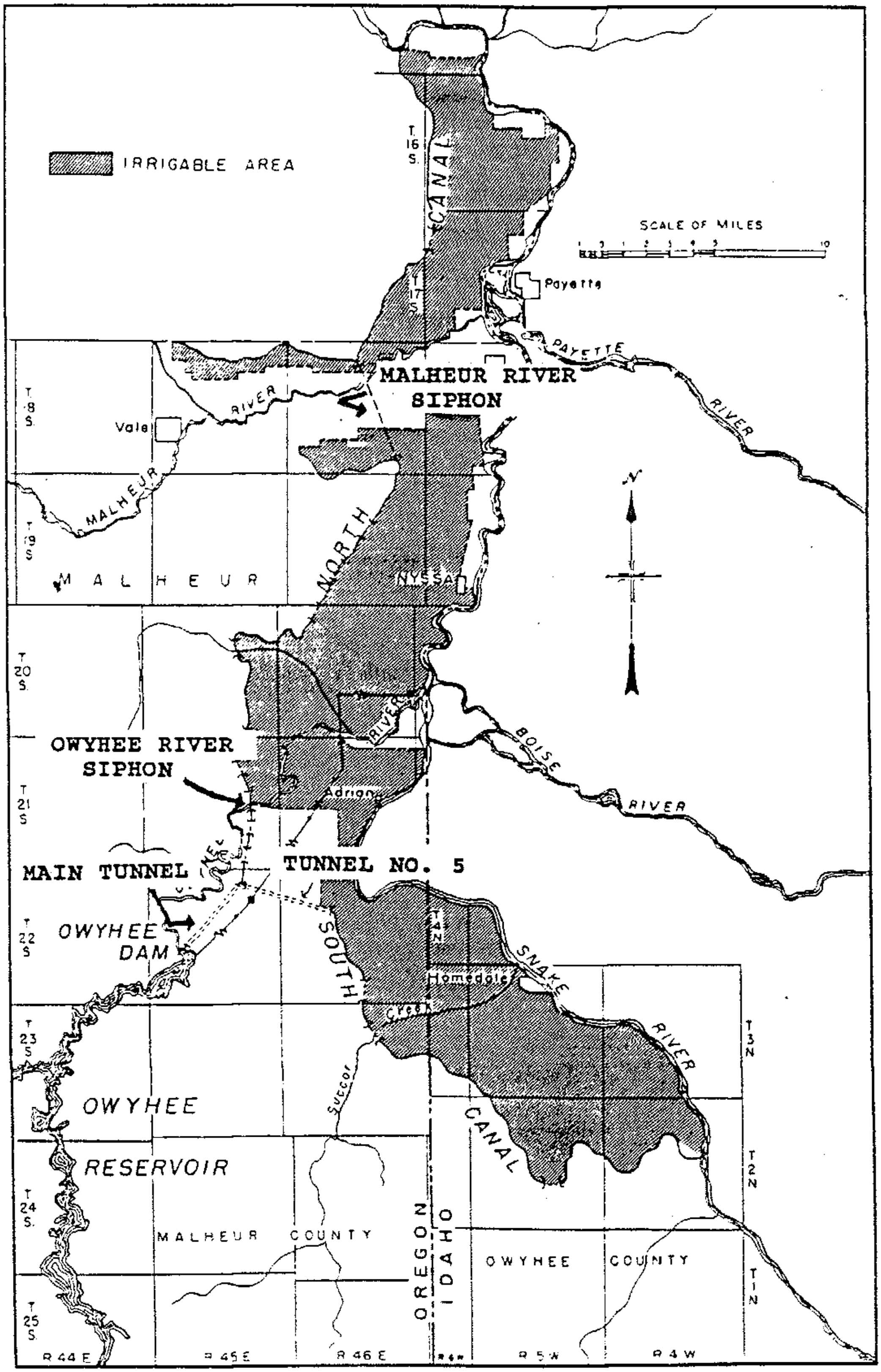
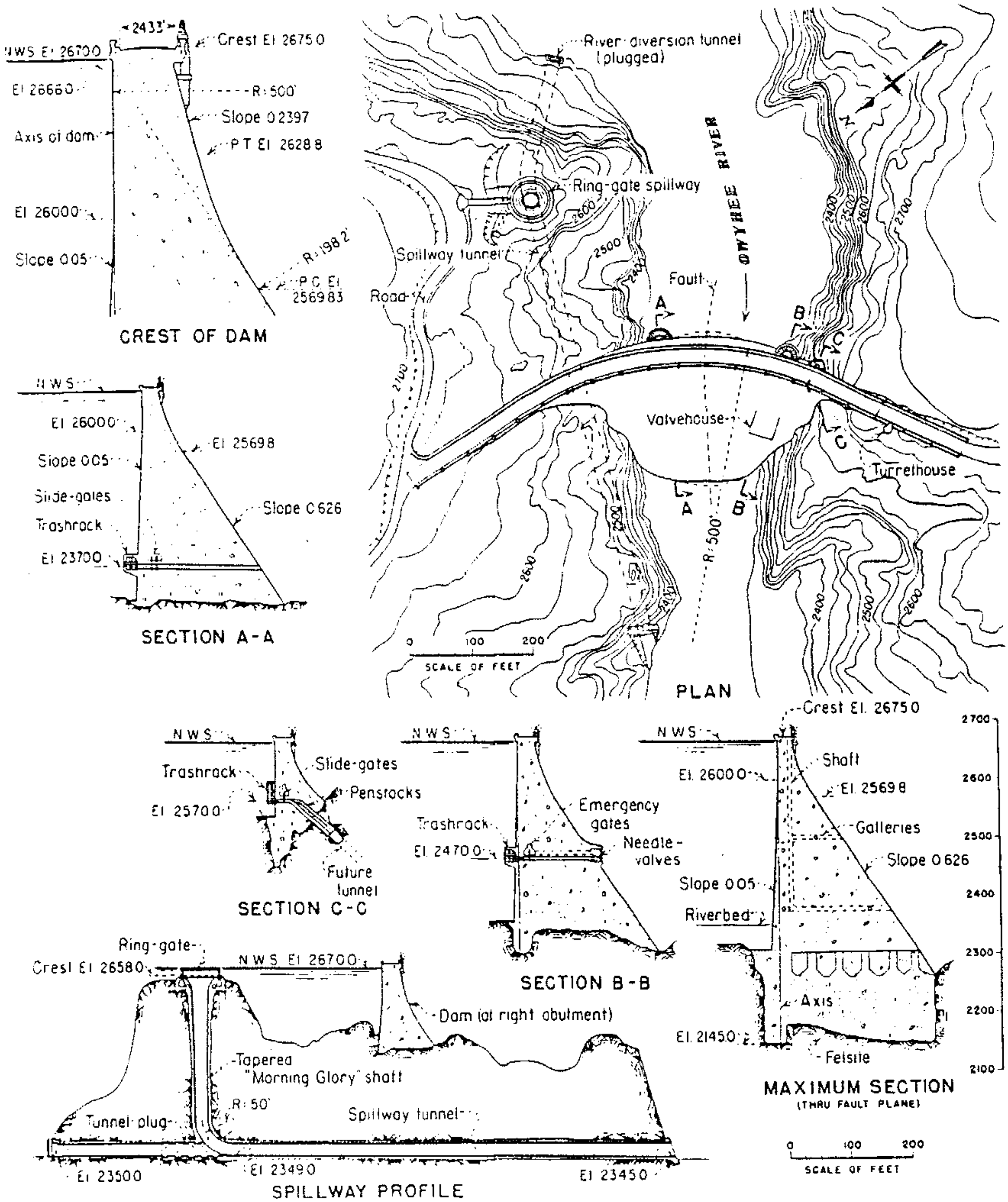
PHYSICAL DESCRIPTION OF OWYHEE DAM

Owyhee Dam was built in 1928-1932 to impound Lake Owyhee as the main storage feature for the Owyhee Irrigation Project. A concrete thick-arch dam with gravity tangent extension, Owyhee Dam was once the tallest dam in the world. It is located about 20 miles southwest of Nyssa, Oregon, and 11 miles southwest of Adrian, Oregon. The dam spans the canyon of the Owyhee River, which is cut through volcanic bedrock consisting of a rhyolitic rock known as felsite. This felsite forms the abutments and foundations for the dam. Rugged, open hills surround the reservoir and damsite. Elevation at the base of the dam is about 2325 feet above sea level, and its crest is at 2675. When filled to the ring gate, the reservoir covers about 12,742 acres with a capacity of 1,120,000 acre-feet of water. Of this, about 715,000 is active storage with the remainder being dead storage. Access to the dam is provided by a paved road which travels up (south) the Owyhee River along what was originally the roadbed for the railroad constructed to haul building materials to the damsite.

Lake Owyhee supplies water to 105,249 acres of irrigated land along the west side of the Snake River in Oregon and Idaho by means of a system which includes 172 miles of canals, 543 miles of laterals, 9 pumping plants, and 227 miles of drains. Water is taken from the reservoir through a 3.5 mile tunnel that has its headworks along the east side of the reservoir about one-half mile upstream from the dam. The headworks have been altered during 1990 by the installation of hydroelectric generating equipment just south of the inlet gates. This construction has caused some alteration to the original inlet gates, but has not altered the exterior appearance of the gatehouse. At the downstream end of the tunnel, water is divided between the South Canal, which supplies the Succor Creek Division about 6-18 miles east of the reservoir, and the North Canal, which supplies the Mitchell Butte and Dead Ox Flat Divisions about 8-40 miles north of the reservoir. The South Canal passes through a 5-mile tunnel between the bifurcation works and the Succor Creek Division. The



Owyhee project.



Owyhee Dam—Plan and sections.

North Canal passes through several tunnels and siphons, including the Malheur River Siphon, a 4.5-mile-long steel pipe 80 inches in diameter that carries water across the Malheur Valley between the Mitchell Butte and Dead Ox Flat Divisions. The outlet works of Owyhee Dam discharge additional water into the Owyhee River, which conveys the water downstream to the Owyhee Ditch, a privately-built diversion taking water directly from the river. Owyhee Ditch existed before the dam was built.

Owyhee Dam has a maximum structural height of 417 feet and a hydraulic height of 325 feet. Prior to pouring the concrete for the dam, loose material in a fault section beneath the dam was excavated down to about elevation 2145 feet. This fault section was filled with concrete; thus the top of the dam is about 530 feet above the lowest elevation in the fault zone where concrete was poured. The dam is 30 feet wide along the crest and has a maximum width of 265 feet at the base. The crest is 833 feet long and consists of a 623-foot arched section and a 210-foot straight gravity dam section at the right abutment. The axis of the arched section has a radius of 500 feet. The upstream face of the dam is slightly battered (inclined) from the base to elevation 2579 feet, and from there is vertical to the top of the dam at elevation 2675. The downstream face of the dam slopes steeply.

The operable features of Owyhee Dam include a spillway, sluice gate outlet works, needle valve outlet works, and penstocks leading to a powerhouse built just downstream of the dam in 1984. All but the spillway are located within the concrete dam itself; the spillway tunnel passes through the right abutment. The spillway is of the morning glory type, meaning it is a simple horizontal, circular orifice, and water may flow over all sides of the orifice directly into the vertical shaft. It consists of a ring-gate structure, a vertical shaft 309 feet high and 60 feet in diameter, and a horizontal tunnel which leads to a concrete portal about 300 feet downstream from the base of the dam. The concrete-lined tunnel was first bored to serve as a diversion tunnel, about 1,000 feet long, to convey river water past the dam construction site. The vertical shaft connects the ring-gate structure with the tunnel. When the tunnel was no longer needed for diversion, it was plugged with concrete from its intersection with the shaft 235 feet upstream to the diversion intake. The spillway ring gate was built on a promontory on the east side of the reservoir about 300 feet from the upstream face of the dam. It consists of a concrete base and an operable, floating, doughnut-shaped gate. A control gallery and float well are located in an adjoining concrete pier. A bridge links the pier with the nearby road. The bridge and pier have a steel pipe guardrail, which is original, and there is a roof structure over the pier which was added sometime after the initial construction.

The concrete base of the ring gate houses a chamber in which the ring gate sits. The steel ring gate is hollow, and therefore buoyant, so it can float when the chamber fills with water from the reservoir. The gate sits on pedestals when there is no water in the chamber. Along the top of the adjoining pier, a sliding steel door provides access through the floor into the control gallery, an interior shaft which houses the controls and valves for regulating the level of water in the ring-gate chamber. From the top of the control gallery, spiral stairs lead down into the valve room where the control valves are located. A sliding guard valve regulates the flow of water into the chamber from an intake just north of the gate base. To operate the ring gate, this valve is opened wide, allowing water into the chamber. There are two needle valves, one of which is used to regulate the flow of water out of the chamber while the other serves as a back-up. Unlike the needle valves used in the outlet works of the dam which discharge horizontally, the needle valves in the valve room of the spillway are installed to discharge downward. Moreover, they receive water through the side of the valve housing rather than on axis with the needle and the discharge. Needle valves are used in this application for the same reason they are used for the outlet works: because the amount of discharge can be regulated. The spillway needle valves do not operate under the same high pressure, however, as those in the outlet works.

By regulating the discharge through the needle valve, dam operators can regulate the level of water in the chamber and therefore the level at which the ring gate floats. There are two ways to regulate the discharge through the needle valves: manually or by means of the mechanism in the float well, located in the pier next to the control gallery. A float in this well rises and falls with changes in the reservoir level. The float is connected to the needle valves through a series of pulleys. This system was designed so that the volume of discharge through the spillway could automatically regulate itself as the level of the reservoir changed. Operators have found, however, that it is more effective to manually regulate the needle valves by means a screw stem located on the top end of each. In this way, the operators can manually control the level of the ring gate and therefore the volume of discharge through the spillway.

The sluice gate outlet works, needle valve outlet works, and power penstocks all pass through the dam. Each consists of an intake structure on the upstream face of the dam, conduits to convey water through the dam, and gates and valves. Each concrete intake structure is semi-circular in plan, and supports steel trashracks. The sluice gates are located near the base of the dam at elevation 2370; their intake is located approximately where the east bank of the river was originally. The intake for the needle valve outlet works is located at elevation 2470, directly over what was once the west bank of the river. The intake for the power penstocks is located next to the left abutment at elevation 2570, 100 feet below the high water line for the reservoir.

Controls for all of the gates for the outlet works are located in gate chambers, or voids, which were cast in the interior of the dam during its construction. These chambers are accessed by a series of radial and circumferential inspection galleries. The galleries at the base of the dam allowed foundation drains to be drilled and installed after the initial phase of construction. These and other galleries provided access to all parts of the dam for grouting contraction joints and other cracks after the concrete had cured. They continue to allow inspection of all parts of the dam, the gate chambers, and the valve house. Vertical shafts with circular stairs, inclined galleries with stairs, and a freight elevator provide vertical connections between the galleries. Total length of all galleries and shafts in the dam is about 4,200 feet. Four openings provide access to the interior galleries from the outside: one is located along the downstream face at the right abutment near the top of the dam; another is located in a turret along the crest of the dam at the left abutment; the third, which is adjacent to the elevator shaft near the center of the dam, consists of a 5-foot by 8-foot hatch along the roadway which crosses the crest; and the fourth is located near the powerhouse site on the west bank of the river about 200 feet downstream from the base of the dam. The fourth opening consists of a concrete portal leading to a concrete-lined tunnel through the left abutment to the dam interior.

The hatch opens to the top gallery within the dam. The floor of the gallery is at elevation 2648 and is the upper-most stop for the elevator. The elevator shaft extends down to the lowest gallery at elevation 2378. Between the top of the shaft and the crest of the dam is the machine room, which houses the electric motor and elevator hoist. Next to the shaft at level of the top gallery is the transformer room for the elevator's electrical system. The elevator shaft is 8 feet by 8 feet 10 inches. It accommodates a ladder and a counter weight in addition to the 6-foot by 8-foot 7-inch enclosed platform of the elevator car. The car has a steel collapsible gate, and each of the five levels at which the elevator stops has sliding steel doors.

The sluice gates were used during construction of the dam to allow water to pass through the dam during the construction period. When the gates were closed, the reservoir began to fill. Three rectangular, side-by-side conduits, measuring 4 feet by 5 feet, lead from the sluice intake to the gates within the dam. Three 60-inch diameter conduits lead from the gates to the downstream base of the dam. Each conduit has two, 4-foot by 5-foot, cast iron sliding gates operated by oil-driven hydraulic cylinders and arranged in tandem. In each case, the upstream gate is the emergency back-up, while the downstream gate of the pair is the regulating gate, equipped with a spring-loaded brake atop the hydraulic cylinder. The brake can clamp onto the valve stem to maintain a constant opening. In the gate room with the cylinders is the equipment for driving the hydraulic hoists, including an oil reservoir tank, a three-cylinder oil pump, and an electric motor to drive the pump. The gates were manufactured by the Joshua Hendy Iron Works of San Francisco. The gate room is 13 feet 6 inches high; directly over the gates are large slots in the ceiling, 6 feet 6 inches high, to allow free movement of the valve stems. The sluice gates have not been used since the dam went into service. If the reservoir ever had to be emptied, however, the sluice gates would be used to draw the reservoir down after the water level had fallen below that of the needle valves.

Three 4-foot square conduits convey water from the needle-valve intake to the three, 4-foot square, emergency, cast iron sliding gates, also known as guard gates, which serve the needle valves. Like the sluice gates, the guard gates for the needle valves are operated by oil-driven hydraulic cylinders and the assemblies were manufactured by Joshua Hendy Iron Works of San Francisco. Next to the guard gates are smaller, paired, manually-operated valves which allow dam operators to slowly let water into the conduit between the guard gates and the needle valves. The gate room is 13 feet 6 inches high; directly over the gates are large slots in the ceiling, 6 feet 6 inches high, to allow free movement of the valve stems. In the gate room with the cylinders is the equipment for driving the hydraulic hoists, including an oil reservoir tank, a three-cylinder oil pump, and an electric motor to drive the pump.

A needle valve consists of the valve housing and the globular body with a pointed upstream and downstream nose from the which the name "needle valve" stems. The upstream portion of the globular body is fixed in place and the downstream end is moveable. Within the globular body are two distinct sets of chambers, each of which can be subjected to more or less water pressure. If one set of chambers is subjected to greater pressure than the other, the moveable segment of the globular body will be forced against the seat of the valve housing, closing the valve. Under the opposite condition, with the relative pressures in the chambers reversed, the globular body will move away from the seat, opening the valve. A paradox control is located on the underside of the valve housing and connected by a stem to the handwheel of the control stand on the operating balcony above. By turning the handwheel one way or the other, the operator regulates the paradox control, which in turn regulates the relative pressures in the chambers by controlling the rate at which water under pressure from the reservoir enters the chambers and the rate at which water is allowed to drain from the chambers.[1]

Needle valves operate under very high pressure and an extreme hazard may exist if air gets into a needle valve while it is being operated. Therefore, it is important in all phases of operation that the operators make sure there is no air in the system. The presence of air can be observed in sight glasses in the several lines for bleeding air from the system. Operators must follow a complex set of procedures when putting a needle valve into service or when opening or closing it. When putting a valve into service, operators must make sure that the various chambers of the needle valve and the conduit between the guard gate and needle valve are empty of water, that the paradox control is in the neutral position, and that the many controlling valves are in the proper position--closed in most cases. Then the operator must slowly close the needle valve and slowly fill the conduit with water, all the while checking for air in the system and bleeding air from the system, if present, before the guard gate can be opened. To open the needle valve, the operator turns the control handwheel counterclockwise; to close the needle valve, the operator turns the handwheel clockwise. During either procedure, the operator must keep an eye on the sight glasses to be sure no air is present in the system. When closing the needle valve, the operator must retard its motion as the needle approaches the seat to prevent it from slamming shut.

Three 57-inch-diameter conduits lead from the guard gates to Owyhee's three, 48-inch-diameter needle valves, which are located in a concrete valve house built onto the downstream face of the dam. The base of the valve house projects slightly from the dam. Each of the three sides is slightly recessed from its base, corner pilaster, and top edges. Three circular openings, through which the needle valves discharge, are located near the base of the downstream side of the valve house. Directly above each opening is a semi-circular arched window opening, fitted with industrial steel sash. The curved concrete roof, which was cast as a continuous part of the downstream face, has simple stepped projections outward from the sides of the valve house. The two circular openings (about 6 inches in diameter) in the roof were originally installed to accommodate stovepipes for heaters. These holes have since been plugged.

The interior dimensions of the valve house are as follows: 16 feet 2 inches wide (the dimension perpendicular to the face of the dam), 33 feet 6 inches long, and 25 feet high. Each needle valve sits on a concrete pedestal about 8 feet from the back wall of the valve house. Joined to the under sides of the conduits and the valves are a variety of small- and large-diameter pipes used for operating the needle valves. Those with small diameter are bleeder pipes for eliminating air from within the needle valves; they rise to the operating stands above. Those with large diameter are for supplying water to and emptying water from the valves. Drain pipes discharge into sumps in the floor of the valve house. A drain pipe from the sump beneath the middle valve drops down within the dam and discharges into the river channel below water level. Sitting on the floor between the valves and against the back wall are two electric-coil resistance heaters.

About 13 feet above the floor of the valve house and cantilevered from the back wall is a concrete operating platform about 6 feet wide. This is the level at which the entry from the inspection gallery is located. A bridge extends from the platform to the outer wall on the left side of the valve house providing access to the window on that side. In addition to the needle-valve operating stands, which were manufactured by the American Locomotive Company of New York City, the platform houses two wood tool cabinets and one of the banks of data monitoring terminals used for testing the concrete during construction of the dam. An overhead travelling crane runs on tracks along the back and outer walls of the valve house. The 5-ton Armington crane is equipped with a 5-ton Wright hoist manufactured in Bridgeport, Connecticut. The crane is operated manually by means of chains, with lateral movement controlled from the operating platform and transverse and vertical movement controlled from the valve pit.

At the time of documentation (April 1990), the needle valve house had sustained few alterations since the needle valves went into service. One of the needle valves has been altered by replacing the needle with a bulkhead fitted with a 12-inch diameter needle valve. This alteration resulted in no change to the physical appearance of the valve. A more noteworthy change occurred to the controls in the late 1980s. The manual bleeder valves located next to the operating stand for the middle valve were replaced with automatic bleeder valves in an effort to insure that all air is eliminated from the needle valve as a safety precaution to minimize the chance of it exploding. Prior to autumn 1988, the manual bleeder valves for the right needle valve were removed and not replaced and since autumn 1989 the bleeder valves for the left needle valve were removed and not replaced, leaving the middle one as the only operating needle valve at Owyhee. For a description of more extensive changes proposed for the valve house, see page 74 of this report.

The power penstocks consist of two, 6-foot diameter conduits controlled by two, 5-foot by 6-foot cast iron sliding gates. When the dam was built, the conduits extended only 16 feet past the gates into an inclined shaft leading down through the left abutment to the site where it was anticipated that a power plant could be built. When the powerhouse and hydroelectric generating equipment were constructed in 1984, the gate for one of the power penstocks had to be made serviceable--the other penstock would not be used--because it hadn't been used since construction of the dam. Originally equipped with oil tank, pump, and electric motor like the other gate chambers, the penstock gate chamber now has a new oil pump which replaced the other three pieces of equipment in 1984.

Banks of electrical terminals, which were used experimentally to monitor the temperature and volumetric change of the mass concrete during construction of the dam, are still in place at various locations in the gallery system. Two large banks are just outside the power penstock gate chamber, one medium-sized bank is located in the needle-valve house, and two small banks are situated adjacent to doors leading to balconies on the downstream face of the dam. Each bank consists of a rectangular panel of sheet metal housing pairs of terminals. Each terminal consists of a threaded stem and a nut. Wires connected to the terminals on the back of the panel run into pipe conduit embedded in the dam. The two large banks near the penstock gates also have collapsible platforms below the panels for setting equipment while recording data from the terminals.

Several decorative features embellish the exterior of the dam. The turret, which is located at the west abutment along the downstream side of the crest, has a shingled, conical roof. Of cast-in-place concrete poured monolithic with the dam, the turret provides access to a circular stair leading down a shaft to the galleries within the dam. In addition to the steel door at the level of the crest, the turret has three small rectangular windows just under the eaves of the roof. Whereas the parapet along the upstream side of the crest is unadorned, the downstream side of the crest has several ornamental features. Heavy cast iron lamp posts, spaced 47 feet on center, sit on cast concrete pedestals, which project from the downstream face of the dam. Blind, three-centered arches, which support the railing, curb, and a very small portion of the roadway, span between the pedestals. The downstream face of the dam also has a series of small cantilevered balconies at the downstream ends of the radial inspection galleries. The valve house is another prominent feature of the downstream face.

A small concrete powerhouse was built in 1984 adjacent to the portal leading to the interior of the dam through the left abutment. This location, about 250 feet below the base of the dam, is where the designers of the dam anticipated such a structure would be placed. It is equipped with a single, vertical shaft, 4340 kilowatt turbine/generator unit. When this power plant was constructed, the steel lining for one of the penstocks was extended from near the penstock gates through the abutment to the powerhouse. Although the powerhouse is a new feature at the damsite, it is a compatible addition because of its relatively small size and the materials of construction.

HISTORICAL BACKGROUND FOR THE OWYHEE PROJECT

Origins of the U.S. Bureau of Reclamation

In the American West, it has long been recognized that diverting water from rivers to croplands enhances growing conditions, but without seasonal storage of water the benefits accrue primarily during spring and early summer. Western rivers run low toward the end of the growing season when crops still need supplemental water. Yet during spring run-off, much more water flows through the rivers' channels than can be used during the early part of the growing season. Storage of spring run-off saves some water for use in late summer and fall.

The United States government did little to stimulate the development of irrigation in the West until John W. Powell surveyed the region for possible water storage sites and published his findings in his 1878 Report on the Lands of the Arid Region. Powell found small areas already irrigated by simple diversions, but his report demonstrated that many more acres of land in the West could be irrigated through the use of storage reservoirs. In a subsequent article published in Century Magazine (1890), Powell estimated that as many as 120 million acres could be irrigated if all of the reasonably available storage were developed. (Powell was too optimistic: by 1960, some 30 million acres were under irrigation, of which about 22% were part of federal irrigation projects.)[2]

The work by Powell and others aroused growing interest in promoting a concerted effort to increase irrigation in the West. In 1890, the Census Office asked Frederick H. Newell of the United States Geological Survey to conduct a census of irrigated farms. In his report, Newell not only provided numbers, he also described how most irrigation projects were implemented and maintained by individuals or small groups, that there was little evidence of comprehensive management of reclamation activities, and that the result was a haphazard and inefficient system. At about the same time, western railroads, especially the Great Northern, began sponsoring Irrigation Congresses which discussed means and offered resolutions suggesting how the United States could take a more comprehensive approach to developing large-scale irrigation projects. The first major result of these efforts was the passage of the Carey Act of 1894.[3]

The Carey Act represented a transition from total reliance on private irrigation development in the 19th century to 20th century practice in which the federal government took almost total responsibility for some irrigation developments. Under the Carey Act, the United States offered to transfer up to one million acres to each of the western states. The states were then encouraged to organize large-scale irrigation projects by finding private entrepreneurs to build the necessary dams and canals and by selling land to settlers who would in turn buy water from the private developers. Idaho made more extensive, successful use of the Carey Act than any other state. Development under the Carey Act, however, was limited. Although private investors found western irrigation attractive, capital could not be attracted in large enough blocks to undertake most projects.[4]

Despite Idaho's success in bringing large tracts of land under irrigation with the assistance of provisions in the Carey Act, many engineers, conservationists, and politicians from western states pressured Congress to place the federal government more directly in the development of reclamation projects. With the support of a new president, Theodore Roosevelt, Congress passed the Reclamation Act of 1902, which created the Reclamation Service (Service) as a new branch of the Geological Survey. F.H. Newell, who had been Chief Hydrographer for the Geological Survey, was placed in charge of the Service with the title of Chief Engineer. Funded largely by the sale of public lands and staffed largely by engineers, the Service began almost immediately to build large dams, reservoirs, and canal systems, and to establish irrigation districts through which farmers who received water from the federal projects would manage its use. Farmers would also pay for the water they received, theoretically reimbursing the government for the costs of construction and operation. By 1907, more than twenty-five new projects had been authorized and almost 400,000 acres had received irrigation water from project works. Yet private developments continued to play the major role in reclamation, increasing the number of acres under irrigation by almost 6 million between the 1900 and 1910 censuses.[5]

Almost from its inception, the Reclamation Service was fraught with problems. Most difficulties concerned financing. Projects had cost much more than the Service had estimated. As a consequence, the proceeds from the sale of public lands could not meet the Reclamation Service's costs for authorized projects. Furthermore, because projects were costing more than originally estimated, payments from farmers for water were inadequate to pay the costs of systems operations and maintenance and to repay the costs of construction. Congress tried several remedies, including loans from the Treasury to the Service and acts which restructured repayment schedules. In 1907, the Service was separated from the Geological Survey, and in the following years, various plans to restructure the Service were implemented in an effort to improve its operation, all without notable success. In 1923, a new Secretary of the Interior, Hubert Work, abolished the Reclamation Service and created a new Bureau of Reclamation (Reclamation), headed by a Commissioner who was not an engineer. The first Commissioner was D.W. Davis, formerly the Governor of Idaho.[6]

Congress continued to restructure repayment obligations for irrigation projects throughout the 1920s, and occasionally authorized additional money for new projects. Throughout this period, Reclamation and its appropriations were fought by the Department of Agriculture (a rival department) and members of Congress from eastern states, who believed that reclamation was nothing more than "pork barrel" for western states. Others argued that Reclamation engineers were not addressing real needs with their designs, but rather were motivated by the desire to accomplish ever bolder feats of engineering. It was not until the New Deal programs of the 1930s that Reclamation received an infusion of money allowing it to undertake significant new developments. The resurgence of Reclamation was due in part to the skill of Elwood Mead, who had been Commissioner since 1924, and in part to the ability of large reclamation projects to generate construction jobs, a major objective of the New Deal programs. Another important factor in the improvement of Reclamation's financial outlook was taken in 1928, when the Boulder Canyon Project (now known as Hoover Dam) was authorized as a multiple-purpose enterprise whereby fees from water users could be supplemented with the sale of electricity generated at Reclamation dams. Earlier Reclamation projects, such as the Minidoka Project in Idaho, had included generation of electricity among their purposes, but the Boulder Canyon Project was at a scale as yet unachieved.[7]

Despite financial problems throughout its early history, the Bureau of Reclamation and its predecessor, the Reclamation Service, received acclaim for engineering accomplishments which contributed significantly to the evolution of engineering practice in dam design and construction, outlet controls, and water delivery. Reclamation's engineers were based in its Denver office, under the charge of a chief engineer. It was in this office that such engineers as J.L. Savage, Chief Design Engineer, rose to national prominence, designing gigantic structures that set world records for size. He also supervised the design of a broad range of standardized apparatus for use in irrigation projects from the dam to the irrigated farm. Nevertheless, Reclamation also continued to receive criticism from some quarters that its engineers were more interested in designing and constructing engineering marvels than in addressing realistic needs.[8]

Origins of the Owyhee Project

Malheur County, located in southeast Oregon, is drained by two major rivers, the Malheur and the Owyhee, both of which are tributaries of the Snake River. Because of an arid climate, land in the county was best suited for grazing livestock until irrigation projects could be developed. Farmers in the county took an early interest in irrigation, starting small private projects as early as 1881. Malheur County farmers organized both private companies and districts under the Carey Act of 1894, and by 1915 about 120,000 acres in the county were under irrigation, about half of which were cultivated, the rest being in hay and alfalfa.[9]

Soon after its creation in 1902, the Reclamation Service conducted preliminary surveys in search of reservoir sites along the Malheur and Owyhee Rivers. In 1903 when the Service surveyed the area, the only irrigated lands in what would become the Owyhee Project were about 12,000 acres under the Owyhee Ditch. This early irrigation system was without the benefit of storage. Although the mean annual flow of the Owyhee River was over one million acre-feet, most of this occurred between February and May. During the summer months of most years, the Owyhee did not have enough water in it to serve the lands under the Owyhee Ditch. Because the lands along the Snake River near the mouths of the Owyhee and the Malheur were quite fertile and flat, lending themselves to irrigation, farmers in those areas began in 1905 to organize irrigation districts served by water pumped directly from the Snake.[10]

Despite noting the irrigation possibilities along the Owyhee and Malheur rivers in its early surveys, the Service chose to locate its first eastern-Oregon project, the Umatilla, along the Columbia River near Pendleton. Construction of that project began in 1906.[11] The first large storage dam in Malheur County was built a decade later, but it was not a federal project. In 1914, Reclamation Service surveyors investigated the Warm Springs Reservoir site for a Malheur River project, but the Congress did not authorize the project. As a result, the Warmsprings Irrigation District raised private capital for the project, and completed a dam for the Warm Springs Reservoir in 1919.[12]

Straddling the Middle Fork of the Malheur River about 40 miles southwest of Vale, Warm Springs Dam afforded a storage capacity of 70,000 acre-feet of water, which, having been predicated on the region's future agricultural expansion, far exceeded current irrigation demands. Ironically, the storage surplus inhibited -- rather than increased -- agricultural production by encouraging a too-liberal use of water. Since most of the acreage improved for irrigation was poorly drained bottom land, over-irrigation seriously damaged fields and lowered yields. By the time the region's farmers realized their mistake, they were suffering the post-war agricultural recession, and few growers had the money to drain their lands -- or to pay off the bonded debt on the dam.[13]

Faced with financial ruin, the Warmsprings Irrigation District in 1923 offered to sell one-half of its reservoir capacity to the federal government, which would then assume responsibility for developing the Vale region.[14] Reclamation did not develop any projects on the Owyhee or the Malheur until the 1920s. By that time, the agency had begun to seek authorization and funding for both the Vale Project along the Malheur and for the Owyhee Project. The Vale Project was the first to be authorized because of its lower cost. The offer came at a time when Reclamation was under "considerable criticism" for overspending on engineering works.[15] Its commissioner, Elwood Mead, realized that the next project under consideration for Oregon, a major undertaking on the Owyhee River, was not likely to be either cheap or easy to build. In contrast, the Warm Springs proposal seemed virtually risk-free. In August 1924, Mead gave preliminary approval for embarking on the Vale Project: "I am reluctant to undertake Owyhee because of its great cost and tremendous engineering problems . . . . We can get agricultural results so much quicker at Vale and at a comparatively lesser cost. This fact appeals to me."[16]

Despite the fact that the Vale Project was underway, Reclamation did not lose interest in the Owyhee Project, continuing to conduct studies and seek authorization. Because of irrigation developments already occurring in the Jordan Valley, east of the upper Owyhee River in southeastern Oregon, Reclamation Service surveys in 1903, 1904, and 1905 had focused on potential storage sites along the upper Owyhee, upstream from the future site of Owyhee Dam at "Hole-in-the-Ground." In 1909, Arnold and Company, a Chicago engineering firm working for the Boise-Owyhee Company (a private irrigation company) was the first to the identify "Hole-in-the-Ground" as a potential damsite, recommending a diversion dam there and a storage dam about 60 miles upstream at Duncan Ferry. Subsequent Reclamation Service investigations, however, favored a storage dam at Duncan Ferry and a diversion dam at the lower (north) end of the Owyhee Canyon near Mitchell Butte.[17]

J.B. Bond, who was Reclamation's Boise Project Manager, conducted yet another study of possible damsites on the Owyhee River in 1924, and for the first time recommended the desirability of a single dam at "Hole-in-the-Ground." A single dam would allow centralized construction, and one reservoir would reduce losses due to seepage and evaporation. Operation of a storage facility there would be 60 miles closer to the project lands than Duncan Ferry and, therefore, more efficient. Furthermore, the "Hole-in-the-Ground" site was within reach of a railroad.

The first geological assessment of the "Hole-in-the-Ground," completed by Kirk Bryan in 1925, indicated that the reservoir would be watertight and the site was suitable for a high dam. Rock at the site consisted primarily of rhyolite resting on a bed of volcanic tuff. That same year, Bond and Reclamation engineer R.J. Newell produced a design study upon which the present dam is based. The plan revealed a further advantage of the "Hole-in-the-Ground" site: diversion from the Owyhee River would take place at a high enough elevation that lands otherwise irrigated by means of costly pumps could be irrigated with a gravity system. In the area that was being considered for the Owyhee Project at that time, there were about 40,000 acres being served by pumping plants along the Snake in addition to the 12,000 acres under the Owyhee Ditch. Although some of the pumping districts were in satisfactory financial condition, some were in dire straits because of the cost of electricity to drive the pumps. The largest of the troubled areas, the Gem Irrigation District serving almost 25,000 acres and over 200 farmers, was on the brink of abandonment. Reclamation recognized that it could serve these existing projects with water supplied by gravity from a reservoir on the Owyhee, improving their financial condition and at the same time bringing thousands of new acres under irrigation.[18]

In its 1925 report detailing the feasibility of various projects around the West, Reclamation outlined an ambitious scheme for the Owyhee Project. It would be made up of four divisions. Southern-most was the Succor Creek Division, 49,000 acres of irrigable land along the west side of the Snake River and mainly in Idaho. Included in this division were the lands in the Gem Irrigation District. Downstream (north) of this division was the Kingman Division, 8,000 acres of irrigable land flanked by the Snake River on the east and the Owyhee River on the west and north. It included 2,000 acres served by the Kingman Colony pumps. The Mitchell Butte Division was the next division, consisting of 28,000 acres of irrigable land between the Owyhee River on the south and the Malheur River on the north and including the 5,000 acres served by the Ontario-Nyssa pump. The northern-most division was the 30,000-acre Dead Ox Flat Division north of the Malheur River, including about 7,000 acres already served by the pumps of the Payette-Oregon Slope Improvement District, the Crystal District Improvement Company, and the Snake River District Improvement Company. The irrigable lands in this feasibility report totaled 115,000 acres.[19]

Getting water to these lands, however, would require an highly engineered canal system. Water would have to be taken from the reservoir at a high enough elevation to be able to flow by gravity to the various bench lands comprising the project. Reaching these lands would require tunnels through hills separating the reservoir from the areas to be irrigated and siphons across the Owyhee, the Malheur, and other water courses intersecting the canals. In fact, the majority of the $17 million in the proposed budget for construction of the Owyhee Project would be spent on the canal and lateral system. While the dam itself was estimated to cost just over $6 million, the main canal was budgeted at almost $4 million and the canal and lateral systems for the four divisions at another $6 million. The remaining $1 million would be spent on drainage.[20]

One aspect of the "Hole-in-the-Ground" site continued to trouble Reclamation's engineers. Bryan had identified a fault zone in the rhyolite directly under the damsite. He suggested that the fault could be made watertight with proper grouting. Reclamation, however, was concerned that the fault might have experienced recent movement and, therefore, might shift again causing problems of dam safety. In 1927, Reclamation asked Warren D. Smith, a professor of geology at the University of Oregon, to investigate the site and offer a second opinion. His August, 1927, report was fairly discouraging, suggesting that future movement of the fault might be very possible. To get a third opinion, Reclamation retained F.L. Ransome, professor of engineering geology at the California Institute of Technology. In his preliminary assessment, submitted in September, 1927, Ransome stated that further grouting could make the damsite watertight.[21] Additionally:

> Eastern Oregon is not a region of severe or frequent earthquakes, the Owyhee drainage basin is not suggestive of recent earth movements, and the well established even grade of the river is indicative of stability. No one can assert with assurance that an old fault may never move again or even that an entirely new fault may not develop in an unexpected place. We are concerned, however, less with geological possibilities, than with probabilities, within the experience of the next two or three generations. I can see no probability that there will be any movement under the Hole-in-the-Ground damsite (Owyhee damsite) during the next two or three centuries. A gravity dam would unquestionably be safer but is the additional safety necessary or worth the cost? This question the engineer must decide.[22]

Ransome's final report, submitted in October, 1927, verified that the fault was indeed due to movement, rather than to some other cause, such as cooling of the rhyolite.[23] This meant that the only remaining issue for a safe dam was to prevent water from leaking through the fault zone. Ransome's confidence in the stability of the site left it to the engineers to determine the best means to make the fault watertight.

Authorization, Appropriations

The Owyhee Project was initially authorized by an Act of Congress on December 5, 1924. Presidential approval came on October 12, 1926, following reports on feasibility and other investigations of the projected $18,000,000 undertaking. Though the onset of the Great Depression in 1929 had cut funds available for federal projects, the Owyhee and Vale irrigation systems clearly had priority. In fiscal year 1930, the two projects together received $2,796,000 in appropriations, 30% of all money appropriated by Congress for reclamation and 36% of all money appropriated for construction work.[24]

The Owyhee Project was to supply water to 46,000 acres of already irrigated land and 80,000 acres of new lands, with supplemental water storage for the Owyhee Ditch's 12,000 acres.[25] In addition to solving the problems of existing irrigation districts, such as the Gem and Owyhee, the project was intended to offer settlement opportunities to vast numbers of farmers and other Americans displaced by the dustbowl and depression. The government would require annual payments by settlers of $3 to $6 an acre to repay the costs of construction. The Owyhee rate was higher than those of the Boise, Minidoka, or other Reclamation projects in the region, but still "considerably less than is now being paid by irrigators under the pumping units of this project or many other private projects."[26]

Further arguments put forth by Reclamation in favor of the Owyhee and Vale projects were their proximity to the markets of the Pacific Coast and the fact that most of its lands were within eight miles of a railroad and within 50 miles of local markets said to total 85,000 persons. Reclamation's analysts believed that with the expected duty of water of 3.22 acre feet delivered, dairying, stock raising, and growing food crops such as grains, corn, potatoes, lettuce and fruit were all likely to meet with success on the Owyhee lands. A yield of $45.00 per acre per season seemed probable.[27]

The Owyhee Project was not without opponents. In a 1929 issue of New Reclamation Era, H.W. Bashore, a construction engineer on the Vale Project, answered several charges leveled against Reclamation. To the charge that reclamation in Oregon was unnecessary, and would only create unwanted competition for established farmers who were already facing glutted world markets, the author answered that the sorts of crops raised on reclaimed lands were not those, such as corn and cotton, currently suffering on world markets. On the contrary, Bashore argued,

> ...the irrigation farmer furnishes a market for the products of the farmers of the rain belt, and, on account of the wide distribution of these projects throughout the West, a more uniform distribution of population is possible and a direct benefit accrues to all in the rates of corporations serving the public and in increasing the home market for the products of the industrial centers and in furnishing additional opportunities for employment and higher wages.[28]

Another charge answered in the article was that many existing reclamation projects were not yet fully occupied: why build more, critics asked. Bashore responded that many of the farms currently standing empty on reclaimed lands were being held from sale by owners waiting for higher prices. The only obstacle to complete settlement of these lands was not a lack of eager settlers, but selfish landowners holding up the settlement process by keeping their lands off the market. If these idle lands could be offered to purchasers at reasonable prices, Bashore saw no reason that the ongoing efforts by local and state agencies to secure settlers for the region (to be discussed below) could not succeed in bringing Owyhee lands to full and profitable utilization. [29]

The Bureau of Reclamation faced increasing funding problems as the Depression deepened. Congress provided emergency funding in 1931, narrowly averting shutdown of Owyhee tunnel construction and termination of contracts. The federal Moratorium Act cut funds to the Owyhee Project for 1932 and 1933, but the Public Works Fund allotted $5,000,000 in 1933 and work proceeded on Owyhee Dam and the extensive tunnel, canal and syphon system associated with it.[30]

DESIGN OF OWYHEE DAM

To assess the type of dam best suited to the site, Reclamation established a board of engineers, including A.J. Wiley, a prominent consulting engineer from Boise, and J.L. Savage, Reclamation's Chief Designing Engineer in Denver. Savage's engineers examined five alternative designs for the dam: an arch of light section, an arch of intermediate section, an arch of heavy section (also known as an arch/gravity dam), a straight gravity dam, and a curved gravity dam. In their February, 1928, report, the board of engineers recommended the heavy arch: it would cost less than the gravity dams, but offered greater safety than the lighter arch dams.[31] The heavy section arch would achieve cost savings, when compared to the two gravity dam designs, by requiring less excavation of earth, loose rock, and solid rock and by requiring less concrete for construction.[32] Such a design is safe against overturning when considered strictly as a gravity dam, and it gains a considerable margin of strength and safety because of its arched plan. Referring to the location of the dam on a fault, the board of engineers concluded that "any movement which need be anticipated appears to be important as a remote geological possibility, rather than as a historical possibility, and would probably be so small as to interfere but little with complete arch action."[33]

To insure that water would not seep beneath the dam at the "Hole-in-the Ground" site, Reclamation's engineers decided to excavate the fractured rock in the fault along the full width of the dam and to the full depth of the rhyolite. The tuff below the rhyolite was believed to be watertight. The excavated area would be refilled with concrete keyed to the sides of the fault.[34] Reclamation was especially intent on designing an adequate foundation because of the March, 1928, failure of St. Francis Dam, a concrete, curved gravity structure in California. St. Francis Dam had also been built over a fault, and the dam failed when the foundation suddenly failed at or near the fault. F.L. Ransome and A.J. Wiley were both members of the commission which investigated the St. Francis Dam failure.[35]

Historical Context of Concrete Gravity-Arch Dams

From its inception, the U.S. Reclamation Service contributed to advancements in the design and construction of a variety of types of dams, including concrete. Concrete lent itself to several applications in dam construction. A relatively recent construction technology at the time the Reclamation Service was formed was concrete reinforced with steel. It was first used as the material for a dam in 1904 at Schuylerville, New York. Like several other early reinforced concrete dams, the one at Schuylerville consisted of a concrete face supported by concrete buttresses and utilized its shape to transfer the horizontal thrust of the water in the reservoir vertically into the foundation. Such designs were predicated on a desire to conserve materials, but the cost of constructing formwork was great. Consequently, most later concrete dams, including those built by the Bureau of Reclamation, were gravity dams that relied on their own mass, in addition to a proper shape, to resist the horizontal thrust.

The first concrete gravity dam built in the United States was the 1888 Crystal Springs Dam in California. It was designed much like a masonry gravity dam (in which the mass of the masonry resists the horizontal thrust of the water in the reservoir), but concrete was used because suitable stone was not locally available. During construction, concrete was poured in small interlocking segments (called lifts) resulting in a dam 154 feet high and able to withstand the nearby San Francisco earthquake in 1906. Nevertheless, masonry continued to be the predominant material for gravity dams until the Reclamation Service was established. The first dam in the United States constructed of mass concrete was the Shoshone Dam (renamed the Buffalo Bill Dam) in Wyoming completed by the Reclamation Service in 1910. It was not a gravity dam, however, but an arch dam, and at 325 feet it was the tallest arch dam in the world at the time.[36]

The arch has been used for dams since at least the time of the Roman Empire, but it was not used for dams in the United States until 1884 when the Bear Valley Dam, a masonry structure, was built in California. The first concrete arch dam was the 1901 Upper Otay Dam in California. With a height of only 89 feet, it is a rather slender structure, measuring 14 feet thick at its base. The conventional means of calculating stresses in arches was known as the "cylinder method," but there was a great deal of uncertainty among early engineers concerning the stresses which an arch dam would experience, not the least of which was caused by the cantilever action stemming from the dam being fixed to its foundation. As a consequence, arch construction during the late 19th century was only used for relatively low dams. Dams with heights of over 300 feet were designed as gravity dams, but they were sometimes given an arched shaped to provide additional strength in the event of unpredicted, extreme loading.

In the early decades of the 20th century, engineers began to develop more sophisticated methods for analyzing stress in arch dams. The first of these was called the "arch and crown cantilever method," whereby the dam was conceptually divided into several arches. The stresses in each arch could be analyzed individually and in relation to each other. This method of analysis lead to arch dams of variable thickness, and it was used in the design of such unprecedented projects as Shoshone Dam and Roosevelt Dam in Arizona. The latter is 280 feet high, built of a rubble stone core with masonry faces, and is said to have marked the end of the masonry dam era.[37] Many engineers still did not consider the available means of analysis for arch dams adequate. Conservative engineers, therefore, preferred to design conventional gravity dams, although they sometime gave dams curved plans so that the resulting arch action would introduce an additional safety factor. The concrete Arrowrock Dam in Idaho, which when completed in 1915 was the highest dam in the world at 351 feet, is an example of such a dam. Research continued, meanwhile, leading to new tools, such as Lars R. Jorgensen's "constant-angle arch dam" concept used for the design of several Reclamation dams.[38]

An important juncture was reached in 1921 when Fred A. Noetzli, a Swiss-American engineer published an article in the Transactions of the American Society of Civil Engineers in which he clearly identified the problems facing engineers in finding a reliable means for designing concrete-arch dams. He also offered some solutions to the problems. In addition to making a clear statement of the complex forces stemming from the combination of arch and gravity actions, he noted the importance of recording the stresses in a dam resulting from temperature changes during curing of the concrete and from loading as the reservoir fills. The solutions he offered were in the form of methods for separating and calculating the loads in a dam carried by the arch and the gravity systems of the structure. Because the method of calculation involved numerous trials involving different load assumptions, it came to be called the "trial load method." He also recommended that stresses in a dam due to temperature change and loading be measured and recorded, not only during construction, but for several years afterward, not only to be assured of the efficacy of the dam in question but to aid the design of future dams as well.[39]

In 1922, several professional engineering societies formed a Committee on Arch Dam Investigations, with Noetzli serving as secretary. The following year, the American Society of Civil Engineers secured the funding to build and study an experimental, concrete-arch dam on Stevenson Creek near Fresno, California, to determine how such structures actually respond to water loading and other stresses. Reclamation, under the supervision of John L. Savage, undertook the task of measuring stresses in the Stevenson Creek dam so that empirical data could be compared with the theoretical stresses calculated using the trial load method. The tests at Stevenson Creek gave Savage confidence in the trial load method for designing other concrete-arch dams. The first two were Gibson Dam in Montana and Horse Mesa Dam (built by the Salt River Valley Water Users Association) in Arizona. Reclamation installed testing apparatus in Gibson Dam to record stresses during and after construction, as recommended by Noetzli.[40] Reclamation and the Committee also began using scale models to check dam designs against the trial load method. Engineers installed gauges to measure deflection of the models when they loaded, using mercury to simulate the loading the actual dam would experience from a full reservoir.[41]

Use of the trial load method was predicated on the following assumptions:

1. The foundation and abutment rock at the dam site is homogenous and uniformly elastic in all directions, and is strong enough to carry the loads applied with stresses well below the elastic limit.

2. The concrete in the dam is homogenous and uniformly elastic in all directions.

3. The dam is thoroughly keyed into the foundation and abutment rock throughout its contact with the canyon profile, so that the arches can be considered as fixed at the abutments, and the cantilevers fixed at the bases.

4. The vertical construction joints in the dam are grouted, or the open slots filled, before the water load is applied, so that the structure acts as a monolith and arch action begins as soon as the reservoir begins to fill.

5. The horizontal water load is carried by two systems of structural elements, namely, a system of horizontal arch elements and a system of vertical cantilever elements.

6. The total water load is divided between these two systems of load transfer in such a way as to satisfy the conditions of equilibrium and geometrical continuity in all parts of the loaded structure.

7. The total vertical loads, including the weight of the water on the faces of the dam as well as the weight of the concrete, are carried downward to the foundation through the cantilever elements without any transfer of load laterally to adjacent cantilevers by means of vertical arching.

8. Effects of flow can be adequately allowed for by using somewhat smaller values of the modulus of elasticity than would otherwise be adopted.[42]

By permitting a more accurate analysis of structural stability, the trial load method encouraged Reclamation engineers to attempt dams of world-record size, such as Owyhee Dam, completed in 1932, and Boulder Canyon Dam, completed in 1936.[43] And as they used the trial load method more, engineers grew familiar with secondary stresses which should be considered in the analysis of a dam. These included shear, bending within the cantilever and arch components of the dam, and modifications of stresses within the dam resulting from deformation of the foundation and abutments under water loading. These more complex calculations occurred in what was called the amplified trial load method. The amplified trial load method was of particular value to the design of high, massive dams such as Owyhee and Boulder Canyon, in which the secondary stress of twisting was important. Twist action generally leads to a decrease in radial deflection, a decrease in arch stress, a decrease in cantilever stress along the downstream face, but a small increase in cantilever stress along the upstream face. The amplified trial load method gave Reclamation engineers greater assurance that stresses within the dams they designed would be within allowable limits while striving for the most economical designs.[44]

The trial load method was equally valuable for designing more modest structures such as Deadwood Dam in Idaho, where it ensured economy of design, and for analyzing the adequacy of designs, such as Buffalo Bill and Roosevelt, which originally did not have the benefit of the Trial Load Method.[45] By 1938, Reclamation had designed seven of its own dams using the trial load method: Boulder Canyon (now known as Hoover, and hereinafter referenced as Hoover), Owyhee, Parker, Seminoe, Gibson, Deadwood, and Cat Creek. Reclamation and other governmental agencies as well as private engineers had also used the method to design dams for municipal water projects and electrical power utilities in addition to irrigation projects.[46]

Owyhee Dam's Spillway in Historical Context

In addition to being the highest dam in the world at the time, the design for Owyhee Dam had several other notable features. The most visually spectacular is the "morning glory" spillway (sometimes also called a "glory-hole" spillway) with its ring-gate control mechanism. The 60-foot-diameter crest of the spillway is located on a promontory about 300 feet upstream of the dam. It allows water to fall 309 feet to the diversion/spillway tunnel, which discharges water through the right abutment to a portal about 300 feet downstream of the base of the dam. Morning glory spillways are especially well-suited for use in conjunction with dams set within steep canyon walls. Moreover, when a diversion tunnel is driven to conduct water past the dam during construction, that tunnel can be easily adapted to become part of the spillway, effecting cost savings. Morning-glory spillways had been used for earlier, smaller dams, but the spillway at Owyhee was by far the highest. Earlier morning glory spillways either had uncontrolled crests or were controlled with radial gates. With the development of the ring gate design for Owyhee, Reclamation was able to control the entire circumference of the crest. Reclamation submitted a patent application for the ring gate and its control mechanism. Although Owyhee Dam was completed in 1932, the reservoir did not fill to the level where it could spill over the ring gate until 1936.[47]

The spillway at Owyhee consists of a circular weir leading to a spillway shaft opening having a parabolic shape in section. The parabolic opening leads to a shaft with a constant diameter of 22 feet 6 inches. The shape of the opening is intended to minimize the amount of air entrained in the water as it drops into the shaft, thus improving performance. Tests to determine the efficacy of such a shape were first conducted in the United States prior to the design and construction of the spillway for the Davis Bridge Dam, a hydroelectric facility on the Deerfield River in Vermont. Completed in 1926, the shaft for the spillway at Davis Bridge Dam had the same constant diameter as Owyhee's shaft. During the model tests for the spillway, the engineers wanted to see if piers for installing flashboards along the crest of the weir would have an adverse effect on the performance of the spillway. They found that, because the piers served to dampen any tendency for the water to vortex, the piers actually had a beneficial effect. Consequently, when it was decided not to use flashboards, the spillway was designed with sixteen piers around the crest of the weir anyway.[48]

Although the shaft spillway at Davis Bridge Dam was the first of its type used in the United States, comparable spillways had been used in England since 1896 when one was built at Blackton Reservoir. Subsequent shaft spillways in England, like that at Davis Bridge, were uncontrolled. The first shaft spillway built by the Bureau of Reclamation was at Gibson Dam on the Sun River Project in Montana. It was also designed and built in 1926 with an uncontrolled weir, but in 1935, six radial gates, each 12 feet tall and 34 feet wide, were installed around the crest of the weir. These provided extra storage while also allowing the operators to begin discharging water from the reservoir in advance of water reaching the tops of the gates. The radial gates were opened by lifting them, allowing water to pass beneath them. The piers supporting the gates also served to prevent vortex.[49]

Spillway outlets somewhat comparable to shaft spillways, called cylinder gates, had been developed by the Reclamation Service early in its history. Closely resembling the cylindrical valve used in navigation canals, such a gate consists of a cylinder open on both top and bottom and seated on the sill of a circular opening of a shaft at the bottom of the forebay leading to the spillway crest. Like the morning-glory spillway, the shaft for a cylinder gate leads to an elbow and a tunnel through which water is discharged downstream. When closed, the gate prevents water from flowing out through the shaft and water in the reservoir can rise along the sides of the cylinder. Because the force of this water is equal on all sides, an increase in head does not yield a corresponding increase in resistance to opening the gate, as is true with sliding gates. When open, water passes beneath the cylinder and into the shaft. Cylinder gates were ancillary to conventional spillways to allow operators to discharge water from a reservoir in anticipation of flood waters. The Reclamation Service installed cylinder gates at the spillways for Avalon Dam on the Carlsbad Project and Elephant Butte Dam on the Rio Grande Project.[50]

The main disadvantage to radial gates and cylinder gates was that water had to flow under them, meaning that floating debris could become jammed in the opening. An alternative to the radial or cylinder gate for conventional spillways was the drum gate, a long, hollow, water-tight, and therefore buoyant structure designed to sit in a chamber along the crest of the spillway. The chamber was designed to be filled with water. Hinged along one side, a drum gate will float up into a closed position when the chamber is filled with water. When the chamber is emptied, the gate drops back down into the chamber allowing water from the reservoir to flow unobstructed over the top. Drum gates had been installed at such dams as Arrowrock on the Boise Project in Idaho.[51]

In order to provide a control for the Owyhee spillway which did not have the drawbacks of radial gates or cylinder gates, the Bureau of Reclamation devised the ring gate, which "had no precedent whatsoever."[52] Floating, adjustable weirs over shaft outlets had been invented prior to Reclamation's development, but all such mechanisms were intended to float on the surface of the reservoir itself to insure that, as the level of the reservoir changed, a constant volume of fluid flowed over the weir and into the shaft.[53] The ring gate for Owyhee's spillway differed from these because elevation of the floating weir could be controlled relative to the reservoir level, thus changing or even shutting off the flow of fluid over the gate. In this sense, the ring gate was more comparable to the drum gate. Although Bureau of Reclamation designing engineer John L. Savage and senior engineer Phillip A. Kinzie were awarded the patent for the ring gate, numerous staff engineers participated in its development.[54]

Design Considerations for the Outlet Works

As an irrigation storage facility, the main purpose for the Owyhee Reservoir was to store water in the Owyhee River, which had its peak flow in the spring, and discharge that water at a regulated rate during the growing season. To deliver water from the reservoir to the irrigated lands required an extensive system of carriage works which required its own complex engineering. Most of the lands to be irrigated on the Owyhee Project were on bench lands, not the river bottom, and so had to be served by canals taking water out of the reservoir at an elevation much higher than the river. Moreover, some of the lands to be irrigated were outside the Owyhee drainage. To deliver water to them required driving tunnels through the intervening hills. The existing water rights of the Owyhee Ditch, which took water out of the river downstream of the dam, had to be served, but this was a small portion of the water which Owyhee reservoir would deliver for irrigation. To serve this requirement, Reclamation engineers decided to locate needle valves in the downstream face of the dam to discharge directly in the river channel. (For a discussion of the development of needle valves, see the appendix.) For outlet works serving the rest of the project, Reclamation planned to divert water from the reservoir through a main canal tunnel through the canyon wall about a half mile east (upstream) of the dam. The inlet for the tunnel would be located at elevation 2,585, about 85 feet below the high water level of the reservoir. Sliding gates would regulate the discharge into the 16-foot 7-inch diameter tunnel. Access to the gates would be down a concrete gate shaft from a gate house along the shore of the reservoir.[55]

Reclamation's engineers designed the main canal tunnel to be 3-1/2 miles long with its outlet at Tunnel Canyon, a small tributary of the Owyhee River northeast of the dam. A 300-foot-long concrete flume would carry the water across the canyon to a bifurcation structure from which the North Canal, with a capacity of 1,190 acre-feet, would flow towards the Mitchell Butte and Dead Ox Flat Divisions (the Kingman Division had by then been incorporated into the

Mitchell Butte Division). From the bifurcation works to the terminus at the north end, the North Canal would pass through several small tunnels and siphons as well as the Owyhee River siphon and the Malheur River siphon, the latter nearly 4-1/2 miles long. The South Canal, with a capacity of 650 second-feet, would supply the Succor Creek through a 9-foot 3-inch-diameter tunnel 4 miles long. Identified as tunnel no. 5, its intake portal was immediately adjacent to the bifurcation structure.[56]

In addition to the needle valves, engineers designed two other sets of outlets for the dam itself: the sluice gates and the penstocks. The sluice gates are near the base of the dam and allowed water to pass through the dam after the diversion tunnel was plugged and before the dam was ready to begin impounding the reservoir. The sluice gates' only other use will arise in the event there is a need to empty the reservoir. The penstocks are located at elevation 2570 adjacent to the left abutment. The original design for Owyhee Dam did not include a hydroelectric generating plant, but guard gates and the upper ends of the penstocks were designed and installed in the dam at the time of construction so that the hydroelectric potential of the dam could be relatively easily tapped at some future date.

The penstocks were not utilized at Owyhee until 1984. During construction of the dam, chief counsel B.E. Stoutemyer, chief construction engineer F.A. Banks and local project promoter E.C. Van Petten all concurred that to produce power at Owyhee was both uneconomical and unfair to participating irrigation districts. A 1932 memo to chief engineer S.O. Harper from the Bureau's Denver office, summarized the first objection:

> It is extremely doubtful if the lands under the Owyhee project will ever be able to pay half of the construction costs and unless the shrinkage can be made up from power revenues there is certain to be a large loss. The only chance to realize a profit on the operation of a power plant in connection with an irrigation project is to produce surplus power in the winter months for commercial purposes. [At] Owyhee...there will be no water available to develop winter power....[57]

Other Bureau of Reclamation facilities, especially those on the Payette and Deadwood River, were seen as more appropriate candidates for power plants because they could produce power in winter. Further, Van Petten made the point that the only way to produce power for pumping in the Gem District of the Owyhee Project was to waste Owyhee Dam storage water intended for irrigation of other districts. (It is worthy of note that from an irrigation perspective, discharging water from a reservoir during the storage season for the purpose of generating electricity is considered waste.) Following such a course, he asserted to Mead, "would get us and yourself into difficulty." Thus, it was agreed that Owyhee should seek revenues by producing power, but not at the Owyhee Dam.[58]

CONSTRUCTION OF OWYHEE DAM

One of the first priorities for the planners of the Owyhee Dam was the construction of a roadway to the damsite to supply aggregate and other materials. Surveys for the roadway were conducted in 1926 from a camp at Snively Ranch, located on the Owyhee River ten miles below the damsite. Early in the surveying process, the possibility that a railroad might be a more economical alternative was introduced. In August of 1927, bids were opened for the construction of a twenty mile highway and a 22.3 mile railroad to run from Adrian, an Oregon town on the Homedale Branch of the Oregon Short Line Railroad, to the damsite, eleven miles southwest of Adrian. [59]

Of the six bids received for the construction of the highway and eight bids for the railroad, the bid of the General Construction Company of Seattle for the railroad was found to be the lowest at $294,592. Final award of a contract was postponed, however, until studies at the Bureau of Reclamation labs in Denver determined where the best aggregate, sand and gravel for the dam might be found. Judging the native rock at the dam site, gravel and sand from deposits near Adrian and deposits from the Ontario-Nyssa area near Dunaway, the Bureau decided that the Ontario-Nyssa material was clearly the best. This deposit was both large enough to provide enough aggregate for the 540,000 cubic yards of concrete needed for the dam, and naturally graded to sizes appropriate for the concrete.[60]

The decision to use the Owyhee-Nyssa deposit eliminated the possibility of building a highway to the dam instead of a railroad because the distance over which the gravel would have to be hauled would render truck transportation too costly; the railway could be converted to highway after the dam was completed. Final plans adjusted the railroad's distance to 24.1 miles so that it ran directly to the Ontario-Nyssa deposits, rather than to the Oregon Short Line connection near Adrian. On this basis the General Construction Company revised its bid upward to $345,312 and signed a contract with the government for this amount.[61]

The General Construction Company was required to complete the railroad within 330 days. By December of 1927, equipment had been assembled at the Dunaway site, and camps, terminals, and supply depots established. In January, 1928, construction began, with tunnels and many of the lighter grading and filling jobs sub-contracted to local companies. The first eleven miles from Dunaway were relatively easy to construct, with heavier work thereafter. The maximum grade going toward the dam was 0.5% and away from the dam, 1.0%. The roadbed was 20 feet wide in cuts, and 14 feet wide in fills. All construction materials were supplied to the contractors by the government.[62]

Ties and bridge timbers were delivered to the railroad site in April, 1928, and by September, all grading was complete. Laying of 70-pound track proceeded steadily, and ballasting commenced at the lower end of the line. Some delays followed a major slide on July 31st near milepost 20 in which the hillside above the roadbed was affected for almost 500 feet back. Nonetheless, the railroad was completed on schedule and for around $100,000 less than the original estimated cost. The first train into the damsite camp was run on October 24, 1929.[63]

The construction of the railroad used an average of 117 men, four trucks and twenty-five teams at any given time. Common labor was paid $4.00 a day, with $1.50 deducted for board and lodging. An additional $1.00 per month was deducted for hospitalization. Equipment utilized included three power shovels, one 70-ton standard gage locomotive, eight 10-yard dump cars, four 40-yard ballast cars, one pile driver and a track laying machine.[64]

On December 7th, 1928, the Owyhee Railroad was turned over to the General Construction Company, by then the main contractor for the dam itself. The railroad remained in their control until November 1, 1931, at which time operation was turned over to the government. Reclamation dismantled the railroad shortly after completion of the dam and converted the roadbed to a highway. In 1931, the engineers of the Hoover Dam requested a detailed account of costs and the construction history of the Owyhee Railroad for purposes of planning and operating Hoover's construction railroad.[65]

Mixing/Screening Plant, Cableway, and Pouring

The on-site preparations for concrete work at Owyhee Dam began with the construction of a testing lab and field office in 1928. The lab, slated to test materials for both tunnel and dam construction, held a 200,000-pound Olsen testing machine, Toledo scales, a Ro-tap sieve shaker, a briquette tester, and other standard equipment for the evaluation of concrete mixes. In 1929, erection of screening and mixing facilities began along the west side of the canyon downstream from the dam. By April of 1930, the screening plant was in operation, and in May, the concrete mixing plant opened.[66]

Sand and gravel for the plants was stripped at the Dunaway deposits by the General Construction Company using a 3-yard dragline. Trains of approximately twenty 30-yard gondola cars, hauled by steam locomotives, delivered the material to the Owyhee screening plant. By 1931, 800,000 tons of aggregate had been hauled from pit to damsite, at a cost of $.0033 per ton mile, or $.16 per cubic yard.[67]

At the screening plant, sand was washed in a "Bodenson" washer, and course aggregates sorted through round-holed screens into four sizes, ranging from gravel 1/4 to 3/4 inch in size to cobbles of 6 to 8 inches. A sand reclaimer was installed beyond the washer to prevent waste of the finer particles.[68]

After washing, the aggregate was carried up to mixers by endless belt conveyers that traveled from beneath the center of aggregate stock piles to storage bins above the mixers. Cement was unloaded at the mixer from tight box cars by bucket conveyors--up to six box cars per day when the maximum of 2500 cubic yards of concrete per day was being produced. The cement was stored in an elevated concrete silo built against the canyon wall, and delivered into the weighing hopper by a screw conveyor. Water was added to the

aggregate and cement in the mixer with a 3-inch hot water meter controlled by a quick-acting valve.[69] The actual mixers were two 4-yard Davis mixers, capable of producing 1,100 cubic yards of concrete in an 8-hour shift. From the Davis mixers, the concrete was dumped into pairs of 4-yard steel hopper cars, and hauled by a standard-gage, 8-ton Plymouth gas locomotive about 1500 feet to three loading docks on the dam's left upstream face for dumping by gravity into cable-carried buckets. The steel cars full of wet concrete arrived at the loading docks at a rate of about one every four minutes.[70]

The mixing plant, which operated on a batch, rather than on a continuous basis, was used to create several different blends of aggregates and cement. Materials were carefully weighed by Toledo scales that measured to the nearest ten pounds in the case of aggregate and to two pounds for cement. Trident water meters could measure water to one-eight of a gallon. The measurement of materials for concrete by weight assured a greater degree of uniformity in the final mix than did the previously preferred method of measuring by volume.[71]

A different recipe was followed for each portion of the dam, providing as dense a mixture as possible for the type of feature being poured. The recipes ranged from 2.7 parts sand to 1 part cement for the mass concrete areas to the much wetter ratio of 1.55 sand to 1 part concrete for the spillway shaft. Slight adjustments to these recipes meant that almost the entire pit yield, no matter its composition, could be utilized (the contractor received payment only for that aggregate which was used in the dam, not for any that was delivered but left unused). In general the natural grading of the deposit's yield closely met the dam builders' needs: so few stones exceeded 8-inches that a crusher installed at the plant ran only about an hour a day. Concrete for the Owyhee tunnel linings used only aggregate below two inches in size, so some additional crushing was conducted when the natural range of graded aggregate did not meet tunnel needs.[72]

In their first year of operation, both screening and mixing plants were considered by dam engineers to be "very suitable and efficient." All bearings used in the screening plant machinery were "self-aligning," able to correct for slight settlement in the structure. During the shut down of concrete work during the winter of 1930-31, some routine maintenance, including relining of the mixers, was undertaken. The proximity of the concrete plant to the dam meant that there was no room to erect facilities for drainage of sand prior to mixing, but according to project reports, this was a deliberate choice. Rather than erect the concrete plant farther away so that drainage processes might be included, engineers chose a set-up that allowed very close control over the condition of concrete coming to the dam. Results of inspections of concrete arriving at the dam's cableway loading docks could be readily fed back and translated into adjustments at the mixer. Tests frequently conducted in the Owyhee concrete labs included those for slump (a slump of 3 inches at the mixer was found to equal a 2-inch slump at the dam), impermeability, absorption, and heat generation. During 1931, reports were issued from the Owyhee Dam labs on the results of experiments with different mixing times, blends of different brands of cement, and the addition of varying amounts of lime. While some of these reports dealt strictly with topics concerned with local quality control, like the effect of mixing cements originating in Utah and Oregon, other reports, such as one dealing with the effects of lime on heat generation in concrete, had broader applications, especially in providing technical support for the design of Hoover Dam.[73]

The tracks for hauling concrete from mixer to dam ran along an embankment on the west side of the river formed from dumped excavations of tunnel headings. Locomotives started carrying materials on the tracks in October of 1929, bringing up supplies, and carrying away materials removed during excavation for the foundation. Excavated materials were loaded by steamshovel into the buckets of a cableway system erected to serve as the primary transport system in the dam area, for removal of waste and delivery of concrete.[74]

The cableway was installed by the Lidgerwood Company, and is sometimes referred to in construction documents as the Lidgerwood cable. The system consisted of a 3-inch track cable that stretched 1300 feet across the river between a headtower on the east side of the canyon and a tailtower on the west. The cable could carry a loaded 8-yard bucket full of debris or wet concrete, or skips loaded with workers. To enable the cable to serve all portions of the damsite, the headtower was set on a 550-foot-long track laid along an arc of 1,300-foot radius centered on the stationary tailtower. The headtower, built of wood, stood 65 feet tall and weighed about 400 tons. The tail tower was a bolted frame carrying an oak bearing block. Just before reaching the tower, the main cable divided into two lines, passing over the bearing block and continuing to two separate anchorages. This arrangement provided direct tension on the cable regardless of where the headtower was located along its track across the river.[75]

The main cable, on which the weight of the moving carriage rested, was constructed of plow steel with a steel core. The button cable, strung below the main cable to pull the carriage back and forth, was 3/4-inches in diameter with a hemp core. The haul line, on which the buckets or skips traveled up and down, was also 3/4-inch and moved at 300 to 500 feet per minute. The button line ran through the headtower, and was regulated by a heavy coil spring, with which it could be kept parallel to the main cable. The cableway could carry a load 30 feet above the top of the dam.

A 400-horsepower motor drove the main hoist of the cableway, consisting of two 54-inch drums equipped with air operated friction clutches and brakes. The air was supplied by two 15-horsepower automatic compressors. The headtower was moved on its tracks by a 75-horsepower motor at a maximum of 200 feet per minute. It rested on 17 pairs of 24-inch steel wheels, nine pairs supporting the forward track and the others carrying counterbalances. The cableway was controlled by an operator stationed in a pilot house. This house could be moved from one vantage point to another, depending on which part of the dam was being worked on, and at times was suspended on cables above the damsite. The operator used six levers to control the cable, four for friction clutch and brake release, and two for the control of the two motors.[76] The headtower burned beyond repair on June 25, 1929, but a replacement was completed and put into service on December 10, 1929.

The cableway, defined as a hoisting and conveying device, was a well-established technology for moving material to and from dam construction sites. The cableway is said to have been derived from the tramway, a device which had been used in Europe at least since about 1700 for transporting material over relatively long distances along a rope, wire, or cable supported on intervening towers. But whereas the tramway had no capacity for hoisting, the cableway could move material vertically as well as horizontally. A French inventor named Pluchet is credited with the first cableway in 1851, and the device was introduced to the United States shortly thereafter. By the turn of the 20th century, cableways were widely used in mines and quarries. The Lidgerwood Manufacturing Company was one of the major suppliers of such cableways. Reclamation adapted the cableway mechanism for use in concrete-arch dam construction at Arrowrock Dam in Idaho in 1912-1915. The Lidgerwood Company built the basic cableway mechanism and Reclamation's Francis T. Crowe devised a hopper-and-trough apparatus to allow crews to place concrete anywhere along the curved site of the arched dam. Reclamation used the hopper-and-trough system in the 1930 construction of Deadwood Dam in Idaho. The travelling headtower used at Owyhee obviated the need for the trough, allowing the operator of the cableway to deliver concrete in the hopper directly to the spot at which it would be placed. The concept of the moveable headtower, however, was not introduced at Owyhee, having been first used at a slate quarry in Pennsylvania in the 1890s.[77]

Work at the damsite prior to construction of the visible portion of Owyhee Dam was so extensive that the contract for the dam was actually considered 50% complete when the concrete work reached river level. Excavating and filling the keyways and fault zone crevices, perpendicular and parallel to the canyon respectively, took almost a year.

The keyways, 20-foot-deep excavations in both abutments, were prepared between February and October 1929 using draglines, drilling and blasting, steamshovels and manual excavating methods. Excavated material from the upper portions of the keyways was carted away by truck and used to widen the contractor's construction road. Material from the keyway cut-off trenches between the abutments was loaded onto cableway skips and dumped in the pool at the downstream toe of the dam. The largest boulders were carried away by cableways to waiting trains, and then dropped on the banks down river.[78]

By February of 1930, sand, gravel and boulders in the fault zone had also been removed. The first 50 feet of loose alluvium had been removed by dragline, exposing large boulders embedded in felsite and clay that had to be removed by pick and shovel. In April, the dam's consulting board decided that all fault zone material had to be removed to ensure a stable footing and watertight foundation for the dam. A 12-foot by 30-foot shaft was sunk in April and May to elevation 2145, about 200 feet below the river bottom. Concreting of the upper portions of this shaft were necessary before full excavation at lower depths could proceed. Concrete was hauled to the shaft over a trestle along the south side of the canyon, poured into "elephant trunk" chutes 16 inches in diameter, and cast into struts. Downward excavation then proceeded between the struts, sometimes using picks and shovels and requiring reinforcing timbering along the way. The final depth to which material had to be removed before undisturbed rock was encountered was within 2 feet of Reclamation's estimates during exploration.[79]

The preparation of the lower fault zone was a slow process, hindered by crumbling rock. In many places, drilling and grouting preceded the pouring of foundation concrete. Air drills were generally supplanted by diamond drills as the latter proved to be more reliable. Some grouting was done by the "successive method," in which a series of holes were drilled, but only selected ones filled. Later, after that grout had hardened, the remaining holes were grouted. Other grout holes were provided with pipes that would reach upward into the body of the dam once it was poured, to be filled later. Two portable grout mixers and placers were used, employing up to 200 pounds of pressure per square inch.[80] Concreting was accomplished in a series of 117 small pours of 200 cubic yards each, ending in September of 1930. In total, about 41,000 cubic yards of material was excavated from the fault zone, and 35,600 cubic yards of concrete poured to refill it.[81]

As work on the fault zone neared completion, pouring could begin in the cut-off trenches in preparation for the pouring the actual dam. Owyhee Dam was not a monolithic pour, but rather was poured in segments, accomplished by dividing the dam radially into 17 panels, with each panel being about 50 feet wide. The concrete placed to a specified depth in each panel during a given pour is called a lift. Working in succeeding panels allowed the concrete of one lift to cure while crews placed concrete in adjacent panels. Odd-numbered panels were poured in advance of even-numbered panels, causing them to rise in above the even-numbered panels and giving the dam a staggered appearance during the course of construction. It also allowed crews to apply construction-joint sealant against the sides of odd-numbered panels in advance of the even-numbered panels reaching those heights.

During July and August 1930, concreting began in the cut-off trenches of panels no. 4 through no. 8, and on September 23, the "Big Pour" commenced. Once the foundation, an irregular surface, was covered, concrete pouring proceeded through the use of 4-foot by 8-foot wooden forms lined with 20-gage galvanized iron. The forms had to be strong enough to withstand the force of the wet concrete being dumped into them from above and hold up under repeated use. Ten carpenters comprised the crew that set and moved these forms in four foot lifts. Each form was attached to the one below by tie-rods and loops embedded in the older concrete. To minimize leakage at construction joints, horizontal keys about a foot square were formed at 10-foot intervals. Radial contraction joints were formed high on odd-numbered panels. These joints, painted with tar as soon as they cured, would be grouted later by means of 1/2" pipes set in them during construction. Sealing strips of 20-gauge soft copper were positioned at contraction joints 12 inches from each face of the dam, at gallery openings, and across cutoffs at elevations 2300, 2400, 2500, and 2600 feet. These strips were intended to contain grout within the joints during grouting operations after pouring was completed and the concrete had cooled. Copper strips were also placed within the construction joints to isolate special volumetric cavities as part of the concrete-testing program. Drain and uplift pressure pipes were also placed during pouring.[82]

In the limited instances where it was convenient, wet concrete was chuted directly from the three cableway loading docks in panel four, but generally the cableway and bottom-dumping buckets carried the concrete to the pouring location. Loaded, these buckets weighed 18 tons. A worker rode on the bucket, directing the remote cable operator and opening and shutting the bucket by hand. The bucket could travel from the loading dock to the farthest point on the dam and back in about seven minutes. To save time, the bucket rider closed the bottom of the bucket as it traveled empty back to the loading dock for a new load.[83]

The first batch of concrete poured into a form, landing on the pre-cleaned and wetted surface of the older lift below, was proportioned at 1 part cement to 2 parts sand. This grout-like blend was followed by a 6-inch layer without cobbles, and then regular mix until the form was filled. Crews of one to twelve men tramped the wet concrete, using shovels to spread the mix to the edges of the form.[84]

The tops of lifts were cleaned-up after a sufficient curing period, around six hours on hotter days and up to a full twenty-four hours if poured on cool nights. Toward the bottom of the dam, where lifts were much larger, pouring could take eight hours, with clean-up starting on one end while pouring was completed on the other. These lower lifts were placed step fashion, so that more area would be exposed to the cooling air. As soon as a pour was hardened, any soft laitance (the fine particles that rise with water to the surface of fresh concrete) was removed by wire brushing. Hand brooming was eventually replaced by the use of rotary air-driven brooms, developed on the job and found to be faster and more reliable than the older technology. Debris from the finished lift was collected and removed, and tailings washed off the dam with air and water. The amount of cement removed as waste during clean-up operations on the dam was estimated to be 3,000 barrels.[85]

Because of the tremendous heat generated by curing concrete, specifications at Owyhee required that not more than four feet in depth be placed in any 72 hour period, and not more than 28 feet in 30 days. Additional efforts were made to maintain surface conditions conducive to proper curing. In warm weather, exposed faces of newly poured concrete were steadily sprayed with water pumped from the downstream pool of the dam. In freezing weather, the concrete was covered with canvas and warmed with burning coke. Also in cold weather, aggregate and water were steam-heated before being placed in the mixers so that no concrete reached the forms cooler than 50 degrees. Construction joints were kept moist for two weeks after pouring unless adjacent concrete was poured earlier.[86] With the exception of the experimental cooling by circulating water through pipes embedded in the concrete of segments in panels 3, 4, and 8, no efforts were made to regulate the cooling of concrete during the construction of Owyhee other than by means of the scheduling of the pouring of lifts.

With three shifts working on the dam, concrete pouring in 1930 totalled 33,000 cubic yards in October, 47,800 cubic yards in November, and 28,700 cubic yards in December. During December, the sluice gates and outlet conduits were also placed. By the end of the year, when Reclamation and the contractor estimated the work on the dam to be 51% complete, the tops of panels no. 5 through no. 10 were all between 2360 and 2400 feet elevation, having reached the level where lower galleries within the dam were partly completed and sluice gates were installed with their trash racks in place. Panel no. 4 was held at a lower level until April, 1931, to provide clearance at the three adjacent cableway loading docks.[87]

During 1930, dam engineers made some refinements to the cableway system. Though considered very fast and flexible, certain problems had arisen. In September of 1930, the main cable had begun to show a great deal of wear. The cable was replaced, but before placing even another 5000 cubic yards of concrete, the new cable was showing wear. Finally, in December, the entire carriage was redesigned so that eleven, rather than five, sheaves distributed the weight of the bucket over the main cable. This correction proved successful: there was no noticeable wear to the cable after having carried 20,000 cubic yards more. In September of 1931 the main cable was reversed so that the portion near the tailtower getting the most wear now ran through the headtower. The wheels beneath the headtower also required frequent replacement as axles broke when the tracks settled unevenly on the ground. After more than fifty sets of wheels were replaced, the problem was solved by anchoring the headtower with cables to solid rock.[88]

When pouring resumed in February 1931 after fifty-three days of winter shutdown, crews began by placing concrete around the sluice gates and outlet conduits. Approach roads to both ends of the dam were also completed. In April, crews began concreting panel no. 4 where the three loading docks for the cableway were located. The contractor left a small wedge-shaped area in panel no. 4 under one of the docks un-filled to make way for the last of the concrete loading. The wedge would be concreted as one of the last tasks in 1932. In April, crews also poured the concrete adit entrance in the canyon wall just downstream of the left abutment and poured the concrete floor and lining for the tunnel linking the entrance with the galleries within the dam. The cable operator's house was moved in May to the center of the canyon, where, suspended on cables at about elevation 2630, it overlooked the panels and spillway, providing the operator with a better view of the works.[89]

Between July and September of 1931, the needle valve house and its trash-rack structure were poured in panel no. 4. Pouring of this panel had been delayed so that it could function for as long as possible as a cableway loading dock, and, with panel no. 3, could serve as the segment of the dam for conducting the concrete cooling experiments discussed below. Once placing of concrete in panels no. 3 and 4 resumed, they were exempted from the limits on speed of pouring so that work on them could reach the elevation the other panels had reached. In November, the dam's power outlet works and trash rack were finished. By the time work stopped for the winter, panels no. 2 through no. 12 were all up to about elevation 2600, 75 feet from the top. Fixtures within the galleries and gate chambers were placed as pouring proceeded. As of November 23, 1931, when work stopped for the winter, the dam was 91% complete.[90]

Of the fixtures placed in the dam, the irrigation outlet works required the most extensive special construction. Each of the three sets of outlets--sluice gates, irrigation outlet works, and power penstocks--have a trash rack structure on the upstream face of the dam, conduits to convey water through the dam, and hydraulically-operated sliding gates. In addition, the irrigation outlet works have three needle valves, one at the downstream end of each conduit, to regulate the flow of water discharged through the dam. The needle valves are located in a valve house on the downstream face. Crews began pouring concrete for trashrack structure and the valve house of the irrigation outlet works at the same time. Because these structures were not part of the mass of concrete, but rather extended from the faces of the dam, and because they had to meet special tolerances for supporting trashracks, valves, gates and other appurtenances, particular attention was paid to the pouring of concrete for the trashrack structure and the valve house. Richer mixes of concrete (containing higher percentages of cement) were used and the concrete of each segment was allowed to cure for 72 hours before fixtures or subsequent segments were attached to them. As these two structures were being poured, crews placed the sliding gates at their proper location within the body of the dam and then installed the steel conduit linings between them and the trashrack and the valve house. The linings were coated with white lead and then they and the gates were covered in concrete to the level of the floor of the gallery leading to the valve house.[91]

Gates, needle valves, and other fixtures were moved into position by means of the cableway. Items such as the gates, which were to be embedded in concrete, were held secure during pouring by anchor bolts on previously-placed concrete pedestals. After the major fixtures had been placed in the valve house, its roof was poured monolithic with the dam. Crews did not remove the formwork from the roof until work on the dam had reached the point where there was no longer danger of damage to the roof from material falling from the cableway or work on the dam above. In 1932, as work continued on the top portions of the dam, crews assigned to the gates and valves made them operational by installing and adjusting control piping, vents, drains, oil pumps, oil tanks, and control mechanisms. Another major feature installed in the dam in 1932 was the freight elevator, located in panel no. 5. The specifications for the elevator were coordinated with the sizes and weights of the various pieces of equipment within the dam, such as the needle valve body castings, so they could be moved into position either during construction or during later repair or replacement. After the contractor had embedded the necessary inserts in the sides of the shaft as panel no. 5 was being poured, the Montgomery Elevator Company sent a crew of two from its factory in Moline, Illinois, to actually install the elevator and make the necessary adjustments to meet Reclamation specifications. The freight elevator at Owyhee was the first ever installed in a dam; Reclamation considered it an innovation made necessary by the magnitude of the structure.[92]

As work progressed on the dam, other features of the project were under construction as well. The Bureau of Reclamation awarded three contracts to drive the two major tunnels. The J.F. Shea Company of Portland, Oregon, received the contract for the outlet half of the main canal tunnel (tunnel no. 1) and the inlet half of tunnel no. 5, conducting the work for both from a camp in Tunnel Canyon. T.E. Connolly of San Francisco was awarded the contract for the intake half of tunnel no. 1 and S.S. Magoffin of Vancouver, British Columbia, received the contract for the outlet end of tunnel no. 5. Employing miners and using tunneling equipment, the contractors drove their respective ends of the tunnels towards each other. To drive a tunnel, they drilled the work face, set explosive charges, and used a narrow-gauge railroad with a mucking machine (power shovel) at one end to load and haul the blasted rock from the tunnels to dumps outside the portals. The contracts gave Connolly and Shea 1,275 days to complete tunnel no. 1 and gave Shea and Magoffin 1,100 days to complete tunnel no. 5. All completed their work on time except Magoffin, who encountered unexpected fault zones and water under pressure which made the tunnel work difficult to complete.[93]

The Malheur River Siphon was also a monumental undertaking. Over 23,000 feet long and 80 inches in diameter, it had a maximum head of 268 feet and a carrying capacity of 325 cubic feet per second. Reclamation engineers asked for bids for alternate designs for the siphon, one consisting of precast concrete pipe to be buried under ground and the other of steel pipe supported above ground. Consolidated Steel Corporation of Los Angeles submitted the low bid for steel pipe at $522,457, which was about $40,000 less than the low bid for the precast concrete pipe submitted by the American Concrete and Pipe Company of Los Angeles. Awarding the contract for the steel pipe eliminated one concern engineers had with the concrete-pipe scheme: about a mile of the route consisted of alkali ground, which might have an adverse effect on the concrete pipe. It took more than 400 flat cars to ship the steel pipe by rail from Los Angeles where it was fabricated out of steel plate using arc welding. In the field, all joints between sections of pipe were also arc-welded except at expansion joints. High concrete piers supported the siphon where it crossed the river, and it was lined with concrete where it passed under railroad tracks and highways. Otherwise, the siphon was supported about 15 inches off the ground on concrete piers spaced about 60 feet apart. Built according to the same design, the Owyhee River Siphon was much shorter, but had a higher head at 350 feet.[94]

Completion of Owyhee Dam

Pouring of mass concrete was completed on May 28, 1932, and finish concrete work was completed on July 8. The last pours took more time than did earlier ones because of the time required to place formwork for parapets and lightposts. The 8-yard cableway bucket was replaced with a 4-yard bucket for easier clearance at the top of the dam. After the last pouring of mass concrete, at the end of May, the unpoured wedge left in panel no. 4 for the cableway loading dock was completely filled, and the surface of the dam stoned and cleaned by crews working from a skip on the cableway. As pouring ended, metal and wood portions of the mixing and screening plants were taken down (the concrete silos and hoppers of the mixing plant still survive on the canyon wall). Stockpiles of aggregate were left intact for use on tunnels. The cableway was dismantled in July: machinery was salvaged and sold, the wooden towers were burned, and the main cable cut and dropped into the reservoir below.[95]

Owyhee Dam was dedicated on July 17, with approximately 3,000 people in attendance. Fifteen passenger cars loaned by the Union Pacific Railroad transported guests from Dunaway to the damsite. Secretary of the Interior Ray

Lyman Wilbur delivered the dedication address, and the General Construction Company hosted a dinner in the mess hall of their camp. The contractor finished plugging the diversion tunnel in September and completed its contract with Reclamation by the end of October, 4-1/2 months ahead of schedule and within budget. In December, 1932, the sluice gates were closed and storage in the reservoir began.[96]

Completion of concrete work on the dam did not, however, mean that water would be available the next season. On the one hand, there was still much work to be completed on the overall construction of the Owyhee Project. At the end of 1933, extensive work was underway constructing major portions of the canal system and although more than $11 million had been expended on the project, it was as yet only 64% complete. More important, the dam had yet to be grouted. The reservoir behind Owyhee has a large "dead water" capacity, which is that portion of the reservoir which lies below the level of the outlet works. It would take well over a year for the dead water storage to fill. Knowing this, local irrigators had urged the Bureau of Reclamation to plug the diversion tunnel as early as late 1931, hoping that the unfinished dam could begin impounding the dead storage portion of the reservoir before the dam was complete. Such a plan, however, was neither safe nor practical. Once Reclamation plugged the diversion, there would be no means of passing flood water through or around the dam if a flood reached the extreme of that experienced in 1892. Such an event would have several negative consequences on the completion of the project: it would place pressure on the dam causing the construction joints to close before they could be properly grouted; it might fill the joints with silt making proper grouting difficult; and it could raise the level of the reservoir to that of the outlet works, flooding the contractor who was driving the outlet tunnel.[97]

Grouting of the foundation and abutments of the dam had begun in 1932. Grouting of the contraction joints of the dam itself, however, could not begin until the concrete had cooled to 52 degrees F (the mean annual temperature at the damsite). Some of the concrete could be cooled by means of the piping system installed for testing purposes relative to the construction of Hoover Dam (see discussion below). But by far the greater part of the volume of the dam was not equipped with such a system. During winter layoffs, the galleries had been left open, allowing cold air to circulate through the dam. To speed the cooling of concrete which could not be cooled by the experimental piping system, Reclamation pumped cold water from the pool above the dam through the grouting pipes during the winter months of 1932-33 by means of high-pressure pumps. Reclamation forces did not begin grouting the contraction joints until 1934. Consequently, water did not fill the dead storage portion of the reservoir at Owyhee until April 1935.[98]

Construction Camps

The first workers to arrive at Owyhee Dam were surveyors preparing for Owyhee's railroad, construction road, transmission lines and telephone lines in 1926. These surveyors lived at an encampment of tents and temporary barracks ten miles downstream from the damsite on the Snively Ranch. From the Snively camp, all surveying to within six miles of the dam was conducted. The final six miles were surveyed by crews headquartered at the damsite.[99]

In April, 1927, work began on the more permanent government camp at the damsite, located just downstream from where the dam would be erected. The camp was laid out, fenced and landscaped, and construction of homes and dormitories begun, while engineers and drillers lived first in tents, and then in garages until the dwellings were completed. In December, a deep-well domestic water supply with a 5,000 gallon concrete storage tank, and a sewer system were built, followed by a separate irrigation and fire protection system with a 200-gallon-a-minute pump. By January, houses and an administration building were occupied.[100]

Among the structures built at Owyhee for government employees were "Temporary Cottages" measuring 26-1/2 feet by 19-1/2 feet and "Five Room Cottages" measuring 41-1/2 feet by 26-1/2 feet. The former had a screened porch, one bedroom, a kitchen, a bathroom, and a living/dining room. The latter were similar but with two bedrooms. Both kinds of structures were of wood-frame construction, with fireplaces, basements, and built-in kitchen cabinetry. The temporary cottages had 3-ply rolled roofing over the exterior sheathing while the more permanent five-room cottages had horizontal wood siding and were probably meant for long term use by dam operators (several survive). Families living in the houses created lavish gardens, winning prizes at local fairs. A common park area was established at the north end of the government camp.[101]

A "Temporary Office Building," which still stands, was also erected at the government camp. The one-story, wood-frame building has horizontal wood siding, measures 28 feet by 31 feet, has a porch along two sides, and features built-in supply cabinets and counters. When built, the office was equipped with a fireproof concrete vault set slightly below grade.[102]

During 1928, a camp for employees of the General Contracting Company was erected between the government camp and the damsite, previously the site of diamond drilling equipment storage. The contractor's camp included 11 bunk houses for 32 men each, two wash houses, a mess hall, 16 cabins for married employees, store, and hospital, as well as machine shops, oil house, powder house, offices and warehouses. The two camps were served by a post office and community hall/movie theater. Mail and visitors arrived by an "inter-urban" car that ran on the Owyhee Railroad tracks.[103]

During the peak of construction on the dam in 1931, the contractor had employed 274 men in addition to the supervisory and administrative staff. The construction crew was comprised as follows: 15 men worked at the gravel pits, 16 on the railroad, 15 at the screening plant, 26 at the mixing plant, 12 operated the concrete trains leading to the dam from the mixing plant, 12 worked on the cableway, 40 were involved in concrete placing, 44 were involved in concrete cleanup, 38 built and took down forms, 15 worked on the spillway, 13 worked in the machine and blacksmith shops, there were 5 electricians, 3 men operating the compressors and another operating pumps, 2 worked in the warehouse, and 17 maintained and operated the camp. The contractor's camp stood until July 1932, when work on the dam had reached the point where crews could be cut and some of the bunkhouses razed. Family houses were sold to the public for $50.00, and the Owyhee post office closed on July 30, 1933. By October, all buildings at the contractor's camp except a warehouse purchased by the government for operation and maintenance use had been removed or razed.[104]

Each contractor for other features of the project was also responsible for providing his own camp and physical plant for the construction and for transporting materials from the government's Owyhee Railroad to the work site. Shea's camp was perhaps typical. The Shea camp was located in Tunnel Canyon a quarter mile from the tunnel portals. It included eight bunk houses; foreman's dwelling; office; recreation hall with commissary, barber shop, change room and showers, and recreational areas; mess hall; and cook house. Adjacent to the tunnel portals were the powderman's house, blacksmith shop, train dispatcher's shack, concrete mixer, and compressor house. With Shea paying the government freight rates, the Owyhee Railroad would ship building materials, camp supplies, and mail as far as the mouth of Tunnel Canyon where Shea had a siding. He had his own narrow-gauge railroad running from the siding up Tunnel Canyon past the camp to the tunnel portals. It had the same gauge as the track in the tunnels, so the same locomotives could be used for hauling materials up to the job site as were used for hauling rock out of the tunnels. Along the tracks up the canyon was also a road. At the siding was a bulk cement plant and midway up the grade to the camp was the powderhouse. A pumphouse next to the Owyhee River supplied the contractor with water and there were water tanks situated next to the bulk cement storage, the rock waste dump, and the tunnel portals.[105]

Concrete Testing at Owyhee Dam

Prior to beginning its construction in 1931, the designers of Hoover Dam determined that the dam's unprecedented size and planned speed of construction called for thorough field testing of many of its materials and processes. Among the sites chosen, Owyhee Dam, on which construction had been underway for three years, was designated as the site for research on the nature of mass concrete, particularly on the temperature changes and shrinkage cracks attendant in building a structure of such size. Owyhee was also to be a testing ground for methods of cooling concrete. Some research into the mixing of aggregate was also conducted at Owyhee in conjunction with work at the Bureau of Reclamation laboratory at Denver and Purdue University, but the majority of testing at Owyhee for Hoover Dam focussed on measurement of temperature, strain and deflection in mass concrete. The instrumentation that survives in the dam dates from these researches.[106]

The Bureau of Reclamation had been testing its large dams since at least 1905. Borrowing technology that the U.S. Geological Survey had used to study natural rock structures, the Bureau of Reclamation measured the temperature of its masonry dams with thermophones, thermometers that could be placed deep inside a dam and connected by insulated copper leads to telephones or galvanometers on the dam's surface. Other versions of this kind of thermometer, in which the resistance of an embedded metal wire is detected and converted to a temperature equivalent, were considered for use or used in the Pathfinder, Roosevelt, Boonton and Arrowrock Dams. These and subsequent instruments utilized the "Wheatstone bridge," a device that, when temporarily connected to leads on the dams surface, completed a circuit in the instrument and registered the resistance present. Ordinary thermometers were placed in pipelines throughout Shoshone Dam in 1908, giving a rough indication of the amount of heat generated by the curing of concrete.[107]

As steadily larger dams were built in the first decades of the century, the concern with more scientific, and thereby efficient, use of materials increased. By 1926, a dam expressly constructed for testing purposes, the Stevenson Creek Test Dam in California, was being used for the investigation of arch designs and the physical properties of cement and concrete. Built by the private Engineering Foundation to facilitate the work of their "Committee on Arch Dam Investigation" and monitored by the National Bureau of Standards, the test dam incorporated embedded instrumentation. Dr. Roy Carlson, instrumentation engineer for the test dam, developed innovative measurement technologies that were eventually used in the Bureau of Reclamation's ambitious testing program for Hoover. Field testing offered a means by which engineers could compare their design assumptions with actual dam performances, and the opportunity for this kind of comparison was fully exercised in the case of Owyhee.[108]

In 1928, J.L. Savage, Reclamation's chief designing engineer in Denver, began soliciting ideas from instrument manufacturers for resistance thermometers, probably as a normal part of Bureau of Reclamation dam construction, rather than with any thought of preparing for Hoover Dam. The thermometers had to withstand hydrostatic pressure of 250 pounds per square inch and be impervious to moisture. The corrosive action of concrete hydroxides prohibited the use of conventional coverings for electric cables. Copper resistance coils with "armored" cable leads, read by a Wheatstone bridge, had constituted the resistance thermometers at Gibson Dam in 1926 with satisfactory results. Savage sought a suitable version of this device that would last at Owyhee for at least 10 years.[109]

By the middle of 1930, Reclamation engineers were planning to embed 86 resistance thermometers in ten radial groups at seven elevations in panel no. 6 and at mid-dam elevations in panels no. 4, no. 8 and no. 10.[110] The resistance thermometers for the Owyhee Project were being manufactured in Denver, some under contract and some by the electrical division of

Reclamation's engineering office. Each instrument consisted of a thin, insulated copper wire wound into a coil to provide a long wire in a compact package. Changes in temperature in the wire caused changes in electrical resistance. When the thermometer had been calibrated, a measurement of the electrical resistance of the wire could be converted to a temperature.[111]

To allow reading of the thermometer once it was embedded in concrete, a copper lead was attached to each end of the coil before installation. These leads were also embedded in the concrete, and run to junction boxes, and then to terminal boards where Wheatstone bridge "test set" instruments could be connected. A third wire in the thermometer lead cable was also connected to one end of the coil and run to the terminal board. This redundant lead was used to measure lead resistance, which, like the coil resistance, changed with temperature. This measurement was subtracted from the resistance of the leads plus the coil--also ascertained at the terminal board--to give a corrected resistance for the coil (thermometer) alone. At least one internally shorted thermometer with enamel-insulated coil wire was rewound with improved cotton-and-enamel insulated wire, and eventually all new thermometers used this material.[112]

Bureau of Reclamation engineers used and experimented with three types of cable for connecting embedded instruments with the terminal boards during instrumentation of Owyhee Dam. They were: lead covered and armored type "BX" cable of the type used at Gibson Dam; "trench lay armored" cable; and a rubber armored, three-conductor cable with steel strand reinforced conductors. The two basic properties desired were ease of splicing and sealing to the instruments in all types of weather, and the ability to survive the harsh conditions within the concrete, caused by large cobbles and subsequent hydrostatic pressures within the dam. The lead armored "BX" cable came to be considered too fragile, due to the brittleness of the lead armor.[113]

All measurements from electrical instrumentation in Owyhee Dam were taken at terminal boards located in galleries and the valve house. All instruments in the dam were connected by cable to the carefully labelled jack connectors on the ebony, asbestos-backed, formica-covered boards. Technicians carried portable "test set" instruments to the terminal boards, connected the test sets to the appropriate terminals, and recorded measurements on forms printed at Reclamation headquarters. The test sets consisted of portable Wheatstone bridge devices built into oak carrying cases with hinged lids. A Wheatstone bridge is a classic instrumentation electric circuit. In the test sets, variable resistances are adjusted until symmetry is achieved in the circuit, indicated by a "zero" reading on the galvanometer (Ammeter) connected between the two halves of the circuit. When symmetry is achieved, electrical resistance between the connected terminals can be determined from the settings read from the dials on the variable resistances. At Owyhee, this resistance was then combined with other readings for lead wire resistance (all instruments) and instrument temperature (elastic-wire strain meters), and the instrument calibration, to calculate the value of the measured parameter. Using similar devices at Hoover Dam, two men could take from forty to ninety-one minutes to record fourteen temperature measurements. At Owyhee, a Leeds & Northrup "S" test set was used for resistance measurements, and a set of unknown manufacture was used to measure resistance ratios on the elastic wire strain meters.[114]

Thermometers, along with junction boxes and terminal boards were installed in the dam starting in September, 1931. Several terminal boards in the galleries and valve houses survive. Because pouring of concrete was well under way and Owyhee's contractors were committed to a tight schedule, the exact location of the instruments was dependent on when they actually arrived at the damsite rather than on some predetermined location based on testing strategy. Four thermometers were reserved, however, for placement near the upstream face of the dam in order to "subject the leads to as severe a test as possible" when the reservoir was filled and exerting pressure on the dam.[115]

Readings of the resistance thermometers at Owyhee commenced on November 25, 1930, and were taken at terminal boards on the downstream face or in the galleries twice a day for the first week, once a day for the second and third weeks, every second day during the fourth and fifth weeks, once a week during the remainder of the first six months, and every two weeks after that. The 1931 Project History for the Owyhee Dam states that the actual temperature increases of the curing concrete, recorded to January 1932, reached a maximum of 64 degrees Fahrenheit, a finding in close practical agreement with predicted rises.[116]

While the first temperature readings were being taken, plans were proceeding for the development of cooling systems for concrete in Hoover Dam. In January 1931, during a series of meetings at Reclamation headquarters in Denver, the Board of Concrete Experts identified research needs and assigned tasks to five laboratories and two field sites, of which one was Owyhee. Owyhee was initially assigned experiments on mixing of aggregate, cooling during mixing, and cooling of large blocks of concrete placed at low temperatures and kept moist by atomizing spray while curing. The concrete at Owyhee was similar to that to be used at Hoover (proportioned at 1 cement:2.7 sand:6.9 gravel, and containing cobbles up to 8 inches in size, with a water/cement ratio between 1.0 and 1.1). The Hoover engineers concluded that the cracking they observed in Owyhee's concrete was not severe, but that it was "probably due to avoidable rapid drying and cooling" and that "great differences in temperature within short distances in the concrete should be avoided." They cautioned against striving for strength in concrete by the inclusion of greater proportions of cement, and instead sought methods for controlling the rate at which concrete cooled.[117]

The advantages of cooling mass concrete were many. The prevention of cracks caused by volume change was a primary concern, but the possibility of grouting contraction joints while the mass of concrete was in a cooled condition was also desirable for dam strength. Once grouted in a cooled condition, the concrete mass would naturally rise in temperature and place the joints under compression.[118] Another Oregon dam, the Ariel Dam, had been the site of early cooling researches for Hoover in which cold water was allowed to penetrate vertical holes in the concrete of the dam. The results had been measured with resistance thermometers. Limiting the pace at which lifts were poured was also known to provide some cooling effects in dams. At the time Owyhee was begun, Reclamation required that no more than four feet of any lift be poured in any 72 hours period, and not more than 28 feet depth accumulated within 30 days. This limit was adjusted to five feet per 72-hour period in the construction of Hoover Dam, but in any case, the size of Hoover suggested that a much more effective means of cooling would be necessary to create a strong structure free of major cracks and ready for use in a shorter time than its natural cooling period, computed to be 125 years, would permit.[119]

After an investigation of alternative methods--including the cooling of aggregate before mixing, blowing compressed air through the dam, or using precast (and hence already cool) concrete--the circulation of cold water through embedded pipe was chosen as the most promising method. In testing this method at Owyhee, water for cooling could be taken directly from the Owyhee River, or in warmer months, refrigerated before use (no record of such refrigeration exists, however). An initial plan indicated the use of grouting pipes as the sole means of circulating water, but in June, 1931, the concept of installing a larger set of pipes just for cooling gained favor with Reclamation's engineers. A series of experiments along these lines at Owyhee was inaugurated.

Seven horizontal loops of one-inch pipe, totaling one mile in length, were set in panel no. 8 of Owyhee Dam, just below elevation 2500, as concrete was being poured there during the summer of 1931. The pipes were set on horizontal keys, rather than directly on the pre-existing lift, to make sure that as much wet concrete as possible was exposed to the circulating water. The pipes were placed about eight feet apart and river water from a pool below the dam was pumped through at a rate of 10 gallons per minute for 17 days in August. Twenty-two resistance thermometers, embedded in the test mass with leads running to terminal boards in radial inspection galleries and on the downstream face of the dam, recorded a drop of 37.6 degrees F (from 118.4 to 80.8) over the course of the test. The amount of water, and its temperature at intake and outflow, were carefully recorded for use by Hoover Dam engineers.[120]

In March of 1932, a second set of experimental cooling pipes were laid in Owyhee, this time in panels no. 3 and no. 4 around elevation 2600 feet. The area cooled by these pipes was 100 feet long, 82 feet high, and averaged 35 feet thick. Almost forty volume-change instruments of various types were placed within the panels and more instruments measured contraction joint movements at the joint between the panels. Seven-and-a-half gallons of cold river water per minute were pumped through the system from May 13 to August 11. The concrete in the lower two thirds of the cooled area fell approximately 30 degrees F during this period.[121]

Further cooling of mass concrete at Owyhee was initiated after all the concrete had been poured by making use of the 17 miles of 1/2" pipe already in place for the grouting of contraction joints. In the winter of 1932 ice formed in some of the pipes and on the downstream surface of the dam, and the cooling operation was discontinued until the spring. Ultimately, the grouting of contraction joints was held off until April 1934 to allow cooling through the system. [122]

The cooling system finally implemented at Hoover, to accommodate an expected average rise of 40 degrees F over the course of the curing of a lift of concrete, was only slightly altered from that used at Owyhee. Instead of placing 2-inch or 2-1/2-inch pipes hexagonally around 10-foot centers, as had been done at Owyhee, the Hoover engineers used 1-inch pipe in horizontal layers on 5-foot centers.[123]

While cooling methods were being tested and temperatures tracked, other processes within Owyhee Dam were also being recorded through embedded instruments. Some of these confirmed the effects of the cooling experiments, and others the general movements of mass concrete as the reservoir behind the dam filled. These latter tests were to allow Reclamation engineers to compare actual stresses recorded in the dam with those predicted by the trial load method calculations and by the scale models. Roy Carlson designed elastic-wire strain meters, or telemeters as they were sometimes called, for use in panels no. 3 and no. 4. They consisted of a two-piece porcelain core wrapped in copper wire, with an outer coating of rubber. They measured the displacement of adjacent sections of concrete, like other instruments, by registering resistance when connected to a Wheatstone bridge.

Carlson's gauge, based on the principle that changes in the tension of a wire cause changes in the wire's electrical resistance, actually held two coils "so arranged that a movement which increases the tension in one will decrease the tension in the other." Changes in tension in the wires caused definite changes in the electrical resistance of the wires; a wire in increased tension possessed increased electrical resistance. The two coils—called the expansion and contraction coils—were wired with a common end. Leads are spliced to this common junction and to each of the extreme ends of the two coils. The resistance of each coil could be measured at the terminal board. In the field, the ratio of the two coil resistances was measured. This ratio was compared to the ratio for an earlier measurement, and by applying the meter calibration, relative movement (strain) of the two ends of the meter was derived.[124]

Because it measured the ratio of the two resistances within the gage, Carlson's strain gage was considered to be more reliable than instruments that gave a direct, single measurement of a material under strain. The Carlson strain meter eliminated the direct, and potentially misleading effects of temperature on the resistance of the gage's wires. Further, because the strain meter gave distinct readings in the presence and absence of temperature change, it could be used to distinguish deformations caused by temperature from those caused by moisture content and stress. During 1932, Owyhee's strain meters were initially read every two hours. Later, readings were less frequent, eventually being limited to every 15 days "until the instruments broke."[125]

Strain meters were positioned in contraction joints between panels no. 3 and no. 4, where their findings were corroborated by resistance micrometers and invar crack meters. The resistance micrometers consisted of a very fine wire wound around a core, this anchored to one end of the meter. To the other end of the meter there was anchored a contact which makes electrical connection with the coil. Thus the point of contact, and therefore electrical resistance between the contact and the end of the coil changed with relative movement of the ends of the instrument. A lead wire was run from both one end of the coil and the contact point, back through the embedded cable, junction boxes and conduit to the terminal board, where electrical resistance was measured with the "test set." As with the resistance thermometer, a redundant lead was run to one of the instrument terminals to allow a proxy measurement of lead resistance, and thus allow subtraction of temperature effects of the lead wires. The device was about 16 inches in length. Owyhee Dam appears to be a very early application of this type of meter, as initial designs were so unsatisfactory that installation was nearly cancelled in March, 1931.[126]

The invar crack meters consisted of pairs of rods made from an alloy dimensionally unaffected by temperature. The rods were set end to end across contraction joints. One end of each rod was firmly fixed in concrete, while the other ends—those that nearly met—moved freely at the joint under observation. The gap between the rods was actually placed to one side of the contraction joint so that a 4-inch diameter flanged pipe could be run vertically above the gap to the surface of the dam. There, protected from the sun and wind by a canvas shelter, a surveyor's transit, auxiliary telescope, and dials allowed the motion of these rods to be observed. A scale was attached to one rod of each pair, and when a small light bulb was lowered down the pipe from above, readings of shifts as small as 1/1000 of an inch could be made. The insides of some invar rods were also painted white to make reading easier. Seven sets of rods, placed one above the other in a staggered pattern, could be observed through each pipe. A 1932 Bureau of Reclamation report on the invar and strain meter readings records an average contraction joint opening of 0.044 inches when the temperature of the surrounding concrete dropped 30 degrees F in 40 days.[127]

The invar volume meter consisted of two long invar rods, one half inch in diameter, laid end to end and with extreme ends anchored in the concrete of adjacent lifts. An initial .03-inch gap was set between the adjoining ends. As the concrete changed dimensions in the direction of the axis of the rods, the gap between the rods also changed, and was read on a small linear scale supported on a third, short invar rod. In order to allow freedom of movement, the entire rod assembly was encased in 3- and 4-inch flanged pipes and fittings, with slip joints. The instrument was read from the surface, in the same fashion as the invar crack meters. Two pairs of rods crossed under the vertical sight pipe to allow reading of dimensional changes in two directions. The rod pairs were placed slightly off center in the 4-inch pipe to allow visual access to both gap scales through one sight pipe. Each invar rod aligned with the circumference of the dam was 22 feet 6 inches long. Those aligned radially were 15 feet long. Since rods were placed end to end, the combined meters were able to measure dimensional changes in a block of the dam measuring 45 feet circumferentially and 30 feet radially.[128]

Because dams of the magnitude of Owyhee and the methods used to calculate stresses within them were new to Reclamation designers and others involved in the development of the trial load method, engineers tried to devise various means of testing actual conditions for comparison with predicted conditions. Yet another method for measuring movement at contraction joints was attempted in 1931 and 1932. Diamond-shaped portions of some contraction joints were sealed with copper strips and filled with water. The water was drawn off and carefully measured. The process was repeated to detect changes in volume of these areas over time. Resistance thermometers and micrometers were placed in the sealed areas to correlate changes in volume and heat, but it proved difficult to control the water-tightness of the test areas. These tests were deemed "indefinite" and "ineffectual" in the annual reports of 1931 and 1932.[129]

Uplift pressure within the dam was monitored as the reservoir filled by 19 3-1/2-inch iron pipes set in the base of the dam reaching down a few feet into the bedrock. The pipes were spaced at 43-foot intervals and equipped with pressure gauges to be read in the gutters of the lowest radial gallery. These gages revealed a maximum uplift pressure in 1935 of 80 pounds per square inch, somewhat higher than predicted by the dam's designers. Horizontal pressures were assessed by the placement of bags of gravel at joints at 2435 feet and 2550 feet. Pipe of half-inch diameter connected the sacks to water pressure gauges in inspection shafts.[130]

The location and condition of cracks in the dam were constantly studied after they first appeared in the dam in large numbers in the spring of 1931. Logs and graphs were kept, charting the progression, and in some cases disappearance of cracks. Most were measured using simple calipers, sometimes in conjunction with copper plugs embedded in the concrete on either side of a crack.[131] Among the recommendations for reducing cracking made by the Hoover engineers was the use of concrete vibrators. Effective vibration also reduced the amount of cement needed for good flow of concrete, bringing about savings in money, quicker cooling, and ease of placement. At Owyhee it was hoped that the use of Jackson vibrators would "eliminate the steep angle which [the construction engineer has] had to resort to in order to properly bond the batches that make up a 5-foot lift." Demonstrations of the Jackson vibrator for consolidating and tamping concrete were held at Owyhee in July 1931.

Because some members of the Hoover Dam consulting board could not be present at the demonstration, Owyhee Chief Engineer R.F. Walters arranged for movies to be made of the event. The vibrating machines were provided by the Concrete Machining Department of the Electric Tamper and Equipment Company of Chicago.[132]

SETTLEMENT ON THE OWYHEE PROJECT

When the Owyhee Project was being planned, most of the land that would lie within its boundaries was already in private hands. Of the public land, 5,000 acres was State land and 18,000 acres had yet to be patented. Private lands included 12,000 acres under the Owyhee Ditch, 46,600 acres in irrigation served by pumps, 48,000 acres in small, unirrigated parcels, and 10,000 acres owned by the Eastern Oregon Land Company. Settlement of lands on the Owyhee project was promoted by the Bureau of Reclamation and by enthusiastic local supporters. Early in the planning stages of the project, the government made several provisions to ensure successful settlement. Lands on the project were appraised in 1929 at $5 to $15 an acre--a value based on their current, unirrigated condition--and a limit of 160 acres of irrigated land per individual was imposed. When an owner sold lands in excess of 160 acres to new settlers, he had to adhere to the appraised price. If an owner wished to sell a portion of his 160 acres, he had to split any profit on those lands with the government. By these measures the government sought to forestall the "unwise and immensely injurious effect of land speculation...."[133]

The government also required that settlers apply for permission to purchase lands on the project, and produce proof of $2000 capitalization, either in finances or farm implements and livestock, and of two years experience in farming. The job of determining eligibility was given to the "Vale-Owyhee Government Land Settlement Association," an unpaid group of local merchants, farmers, bankers and other businessmen that was established in 1929 with a full-time secretary and office in Nyssa. In addition to interviewing potential settlers, the association held public meetings, produced tremendous quantities of promotional literature and advertising, arranged loans through local banks, and provided the services of a county agriculturalist.[134]

Other promotional efforts were conducted by the Ontario (Oregon) Commercial Club, led by local lumber merchant E.C. Van Petten, an indefatigable booster of the Owyhee Project. Brochures published before the

Owyhee Dam was begun described the crop yields in the area, and the beneficial conditions for raising hogs, cattle and poultry. Information concerning transportation to local and distant markets and descriptions of dairy and egg cooperatives were included. One circular assured potential settlers that by coming to Owyhee lands, "through the action of the U.S. Government you are getting land and water at a fraction of its value—practically a gift." This same publication recommended that incoming farmers buy ten to forty acres of improved land (that is, already irrigated) and forty to eighty acres of new land, so that the farmers could earn a living while improving the new lands "in their spare time."[135]

The private advertisement and promotion of not-yet-irrigated lands met with criticism and concern from Reclamation. Commissioner Elwood Mead reprimanded Van Petten for luring people to Owyhee before it could possibly provide livelihoods. He pointed out that the Minidoka Project in Idaho had attracted settlers well before water was actually available and that many settlers had "left the project broke and discouraged." Van Petten replied that the Commercial Club's advertisements were not misleading, but rather intended to attract settlers to "good cultivated lands under the electric pumps" that were not being farmed to capacity because they were "in the hands of poor farmers." Van Petten and his colleagues wished to "weed out this class and settle the pumping lands 100%."[136]

Whatever the stated intentions of its promoters, the Owyhee Project did not have any trouble attracting settlers for either private or public lands. The public lands offered on the Owyhee Project constituted the largest single opening of land by the Bureau of Reclamation since 1927. There were four openings of Owyhee lands between 1936 and 1938: 107 units were offered on the Mitchell Butte Division in April 1936, 33 on the Mitchell Butte and Dead Ox divisions in March 1937; 50 on the Succor Creek Division in January 1938; and

29 homesteads offered on the Succor Creek Division in November 1939. Before the final offering, the government had received applications for all but 397 acres of 12,460 originally available.[137]

To assist in settlement, the Farm Securities Administration (FSA) offered loans to eligible farmers on both the Vale and Owyhee projects, aiding about 500 farmers in 1938, of whom 350 were migrants. Loans averaged $1,000, and farmers settling in older irrigation districts had need of less money than did settlers on new lands. A 1939 study of the newly irrigated lands by the FSA, the Bureau of Agricultural Economics, and the Oregon State Agricultural Experiment Station concluded that "farmers' needs for loans decreased with the length of their residence on farms," and that after four or five years farming, the Vale-Owyhee settlers "were able to make repayments of their previous loans and capital obligations."[138]

This study also found that in the early years of settlement on Vale-Owyhee lands, farmers increased the size of their productive plant, acquiring more cleared acreage, livestock and equipment, and that there was a trend away from crop rotation systems that would have let the soil "rest" with legume crops. Both actions were intended by farmers to increase current income. Further, the more lands that came under productive irrigation, the lower hay prices fell in the local markets, so Owyhee farmers abandoned hay as a cash crop in favor of livestock. But hay supplies in the region continued to increase faster than demand, and an equilibrium between supply and demand was not reached. Finally, the study showed that the most desirable use of farm lands would be a combination of raising livestock and intensive specialty crops like potatoes, sugar beets, onions, and seed crops. Such a combination would help compensate for shifting prices in these two kinds of commodities, but it was not in common practice at the time of the study.[139]

Farmers on the Owyhee lands lived frugally as they struggled to bring their homesteads into productivity. Despite problems, they were seen in 1939 to have made "surprising advances" and to be generally improving their standard of living over the years.[140]

The original scheme for repayment called for each settler to pay 5% of the annual crop income to the government, with payments to begin in 1940. In May 1926, this plan was replaced with a forty-year, no interest repayment plan. Owyhee's chief engineer at the time, R.F. Walter, was skeptical of the plan, thinking it unlikely that the estimated $150- to $160-per-acre construction costs (the actual final cost was $189 per acre) of the Owyhee Project could be repaid in that time. He pointed to the Boise Project, which, at a much lower cost, had also failed to be repaid in its allotted time. In fact, in 1940 when repayment of the $17,845,605 it took the government to build the Owyhee Project was to begin, a postponement was granted because the new lands had not had "adequate time to be cleared, leveled and otherwise developed." Money was instead collected on the lands on a water-rental basis to offset operation and maintenance. Repayment by irrigation districts, who held "joint liability" for debts to the federal government for the lands under them, was not required until 1946, at which time an annual construction charge of $2 per irrigable acre was commenced for four years, to be followed by a truer cost of about $3 per acre.[141]

Nine irrigation districts on the Owyhee Project had entered into contracts with the United States between October 1926 and September 1936. These included the Owyhee, Gem, Payette-Oregon, Slide, Ontario-Nyssa, Kingman Colony, Bench, Criptal, and Advancement Irrigation Districts. A board of control served as operating agent assessing and collecting charges from the districts based on their acreage of irrigable lands. The flow of water in the Owyhee River was so low between 1931 and 1936 that the plan to use only water delivered by gravity from the Owyhee Reservoir was abandoned for an interim one in which water for the lowest lands on the project would be pumped from the Snake River, with costs spread out over all the Owyhee districts. This seems to stand in contradiction to the many early arguments for the project which saw the use of pumps as ruinous to settlers. It does appear, however, that in the years following the first deliveries of water in April 1935, that settlement of the region was successful.[142]

Towns on the Owyhee Project grew rapidly, doubling or tripling in population between 1931 and 1938. Ontario, Homedale, Adrian, and Nyssa built new schools (some under the WPA) in these years, and in 1938 the Amalgamated Sugar Company completed a $2 million factory in Nyssa. Ontario acquired a $48,000 airport and a $75,000 low-pressure water system that year as well. Women's clubs and the Grange claimed large memberships. New lands on the Owyhee Project bordered older cultivated lands in a narrow strip, so that settlers on raw lands could take advantage of and contribute to the growth of these towns. Rural electrification by the Idaho Power Company proceeded steadily following the first deliveries of water.[143]

The Owyhee Project is easily the largest irrigation project in Oregon. As Oregonians returned to normal life following World War II, their agricultural endeavors were aided by seven Bureau of Reclamation projects. Four of those projects served more that 30,000 acres each: the Vale Project served about 31,000 acres; the Deschutes Project served about 33,000; the Klamath Project, located in Oregon and California, served about 56,000 acres; and the Owyhee Project served about 93,000 acres in Oregon and Idaho. Roughly two-thirds of the irrigated lands in the Owyhee Project are located in Oregon.[144]

CHANGES TO OWYHEE DAM

Alterations to Owyhee Dam Since 1932

Since construction of Owyhee Dam was completed in 1932 and the grouting was completed in 1934, the structure has undergone few alterations. Consultation between Reclamation and the Oregon State Historic Preservation yielded concurrence that the 1984 construction of the hydroelectric powerhouse would have no effect on the historic qualities of the dam. The only other work of any structural consequence on the dam has been the patching of cracks. At the completion of the dam, cracks were observed on the downstream face, but they did not exhibit subsequent activity. Beginning in the early 1950s, new cracks began to appear. The most serious of the cracks were in the area of the elevator shaft, and in 1956, when the level of the reservoir rose above that of the cracks, significant leakage occurred through the cracks. These cracks were patched at the upstream face. By the late 1950s, the Bureau of Reclamation developed a system of monitoring the behavior of the cracks using wire gauges. Since that time, deterioration has also been noticed in the parapet, the lamppost standards, and the roadway along the deck. Repairs have been made to these and subsequent cracks, but the character of the dam has not been changed. Rock falling from the canyon walls has caused other damage to the structure, including the spillway outlet portal and the crest at the left abutment, but again the character of the dam has not been damaged.[145]

Proposed Changes to the Needle Valves

The Bureau of Reclamation has determined that needle valves pose a potential safety threat to operators. Therefore, Reclamation will replace all needle valves, including those at Owyhee Dam, by the operating season of 1991. In the meantime, the operators at Owyhee are using only one needle valve to discharge water from the reservoir into the Owyhee River for use by the Owyhee Ditch. Minor alterations have been made in that needle valve in an attempt to make it more safe until it and the others are replaced.

In January 1984, an operator at the Bartlett Dam on the Salt River Project in Arizona was changing the rate of discharge through a needle valve and failed to follow the proper operating procedures. Air entered the operating chambers of the needle valve and, being under great pressure, caused the needle to slam into the seat and the system to explode, killing the operator. Later that same year, a crew at the Utah Power and Light Company's Oneida Dam allowed air into the operating chambers of a needle valve while they were operating it. Again, the presence of air in the needle valve caused death, this time by erratic movement of the needle leading to rupture of the penstock. In this event four individuals died. These two accidents led to an investigation of safety problems posed by needle valves. The study concluded that the potential for injury and death coupled with the extremely high cost of annual maintenance required to keep needle valves in reliable operating condition made it desirable to replace all needle valves at Bureau of Reclamation dams with jet-flow valves. Cost estimates indicated that it would cost between forty and sixty percent more over a fifty-year period to continue maintaining needle valves than to remove and replace them and to maintain jet-flow valves for fifty years.[146]

After considering demolishing the roof or the valve house to make way for the removal of the needle valves and the installation of the new jet-flow valves, Reclamation decided instead to remove the needle valves through the freight elevator and install the new valves by the same route. In an effort to minimize damage to the valve house, Reclamation engineers modified the specifications for the new valves so that they will be manufactured in pieces small enough to be lowered into the hatch through the crest roadway to the freight elevator within the dam. From there, the valve pieces will be lowered to the level of the outlet works and transported through a gallery to the valve house. Likewise, the existing needle valves will be disassembled into pieces in the valve house, and removed from the dam by means of the gallery, the freight elevator, and the hatch. The operating controls for the old valves, known as position pedestals, will also be removed and replaced during the course of this work. The overhead crane in valve house is capable of removing the pieces of the needle valves and installing the pieces of the hollow-jet valves. Moreover, the hollow-jet valves are of a size and shape that modification of the interior of the valve house will need no alterations other than the removal of a portion of the control deck over the valves.

Project Statement

This HAER documentation of Owyhee Dam was prepared by Renewable Technologies, Inc. (RTI) of Butte, MT, under contract to the Pacific Northwest Region of the Bureau of Reclamation as part of the mitigation of the adverse effect to be brought about by the replacement of the needle valves. The large-format current-view photographs which are a part of this documentation were taken by Clay Fraser of Loveland, CO, under a separate contract. The rest of this documentation package was prepared by RTI. Fredric L. Quivik, architectural historian, conducted the field recording in April 1990 and wrote the physical description of the dam. He was assisted by historian Amy Slaton in researching and writing the historical portions of the narrative during the summer of 1990. Ms. Slaton prepared the section of the narrative pertaining to concrete testing with the technical assistance Dan Hagan, mechanical engineer of Sante Fe, NM, who worked on the project under a sub-contract to RTI. Mr. Hagan assisted Ms. Slaton with the research in Reclamation records at Denver pertaining to concrete testing at Owyhee. He contributed verbal suggestions on how that section should be written, and then after Ms. Slaton had drafted the section he reviewed it for technical accuracy. Ms. Slaton and Mr. Quivik selected the historic photographs and engineering drawings which form a part of this documentation. Lynne MacDonald, Reclamation's Technical Representative for the contract, provided significant editorial recommendations on the narrative.

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135. E.C. van Petten to Elwood Mead, Commissioner, 14 August 1928, file 270, box 886, entry 7, RG 115, NARA.

136. Elwood Mead, Commissioner, to E.C. Van Petten, Ontario, Oregon, 2 August 1928; Van Petten to Mead, 14 August 1928, both in file 270, box 886, entry 7, RG 115, NARA.

137. U.S. Department of the Interior Press Release, 9 March 1939, file 506.02, box 887, entry 7, RG 115 NARA; "Owyhee Project Being Settled Rapidly, The Reclamation Era 29 (April 1939): 36; Ferd Schlopkohl, "Owyhee Project, Oregon-Idaho," Reclamation Era 25 (March 1935): 48.

138. Carl P. Heisig, "The Migrants, II: New Farms on Newly Irrigated Land," Land Policy Review (November-December 1939): 11-12.

139. Ibid., 14-15.

140. Ibid., 15-16.

141. R.F. Walter, Chief Engineer, to Elwood Mead, Commissioner, 30 August 1926, file 301, box 882, entry 7, RG-115, NARA; U.S. Department of the Interior, How Reclamation Pays (Washington, DC: U.S. Government Printing Office, 1947) 207; U.S. Department of the Interior, Bureau of Reclamation, Economics and Statistics Division, Branch of Operation and Maintenance, "Preliminary Report on Economic Investigation of the Owyhee Project," 1946, report on file at Bureau of Reclamation, Pacific Northwest Regional Office, Boise, i.

142. "Preliminary Report on Economic Investigation of the Owyhee Project," 1-3.

143. "Settlement of the Owyhee Project," 20 February 1939, file 510.221, box 888, entry 7, RG 115, NARA.

144. Bureau of Reclamation, How Reclamation Pays (Washington, DC: U.S. Government Printing Office, 1947), acreage and crop data for the various Oregon projects are listed on the following pages: Baker Project, 6-7; Burnt River Project, 44-45; Deschutes Project, 67-68; Klamath Project, 118-119, 125-126; Owyhee Project, 208; Umatilla Project, 280-281, 284-285, 287-288, 290; Vale Project, 296-297.

145. Engineering Research Center, Water Power Resources Service, Department of the Interior, "Report on Safety of Dam and Appurtenant Works: Owyhee Dam," report for Owyhee Dam on file at the Engineering Office, Denver, 14, 38-41.

146. Bureau of Reclamation, "Owyhee Dam Needle Valve Investigation Report," December 1987, report on file at the Bureau of Reclamation, Pacific Northwest Regional Office, Boise, pp. 4-5; Carol DeAngelis, "Reclamation Replaces Needle Valves, Promotes Safety, and Saves Money," Water Operation and Maintenance, Bulletin 144 (June 1988): 1, 3.

APPENDIX: **Development of Needle Valve Technology**

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Note: This history of the development of needle valve technology was originally prepared by Hess Roise and Company for the Bureau of Reclamation under a sub-contract to FRASERdesign of Loveland, Colorado, as part of the Historic American Engineering Record documentation of Deadwood Dam in Idaho (HAER No. ID-18).

Simply defined, a needle valve is "a valve having a circular orifice which is closed by a conical plunger." As San Francisco inventor William A. Doble discovered in the late 1890s, the mechanism was well suited for controlling high-pressure jets of fluid, such as those used in powering impulse water wheels. In 1900, Doble received a patent for the design of a nozzle containing a mechanically-operated control plug, or "needle." The needle tapered to a point at each end, a shape that helped to guide the discharge into a tight jet. By sliding the needle backward to open the nozzle or forward to close it, the valve increased or decreased the discharge, while maintaining a steady compact spray. Doble's patent eventually became the property of the Pelton Water Wheel Company of San Francisco, the country's main manufacturer of impulse turbines.[1]

Although originally conceived as a means of controlling the power of a jet, Doble's invention was equally useful for controlling the volume and rate of flow, crucial considerations in irrigation engineering where it is necessary to regulate carefully the discharge of water from a storage dam. When Reclamation embarked on its dam-building program in the early 1900s, the conventional control for a dam outlet was some form of sliding, rolling, or rotating gate, usually designed for pressure heads of less than 50 feet. But no control gate had yet been asked to operate under the extremely high water pressures planned for such initial Reclamation projects as Roosevelt Dam in Arizona and Pathfinder Dam in Wyoming, respectively measuring 284 feet and 218 feet in height. Adapting available technology, Reclamation selected gate-type outlets for both Roosevelt and Pathfinder, completing installation by 1909. At the same time, the agency sponsored research into alternate outlet designs, including needle valves.[2]

The needle-valve investigation was the responsibility of Reclamation's chief electrical and mechanical engineer, Orville Hiram Ensign. Born in Ithaca, New York in 1863, Ensign belonged to a generation of engineers whose professional education was largely a matter of on-the-job training. His own formal studies consisted of two years of "mechanical arts" at Cornell University. After entering the work force in 1882, he went from locomotive manufacturing to electrical-machinery production to hydroelectric-plant construction, transforming himself in the process from machinist to factory inspector to consulting electrical engineer. When Ensign took over Reclamation's emerging hydroelectric program in 1904, he already knew a good deal about needle valves, having just invented, and sold to Doble, a safety device for dissipating needle-valve spray.[3]

In February 1906, Ensign presented Reclamation with a rough sketch of a needle valve for releasing high-dam storage. Unlike Doble's nozzle, Ensign's device, which came to be called the "Ensign valve," was designed for the upstream end of an outlet. Its location was dictated by a basic engineering principle of the period, which held that pressurized water should generally be excluded from a dam interior lest accidental leakage destabilize the structure. The purpose of a control gate, therefore, was as much to keep unwanted water from entering the outlet as it was to provide safe passage through it. Ensign wholely subscribed to such thinking and originally referred to his invention as a "gate."[4]

Ensign's invention differed from Doble's needle valve in another important respect as well. Unlike the earlier nozzle, which required external mechanical force for operation, the Ensign valve was hydraulically actuated by reservoir pressure, thereby eliminating the need for motors and mechanical linkages that were difficult to power and maintain at remote dam locations. Under most conditions--whether closed, partially open, or completely open--all parts of the valve were subject to the same water pressure, and all parts were therefore stationary. To effect movement in the valve, it was necessary to unbalance the water pressure in part of the device. Ensign achieved this in such a way that the valve tended automatically to restore its own equilibrium of pressure. The goal was a self-regulating device that would reliably maintain its setting.

Fabricated from iron, steel, and bronze castings, the Ensign valve basically was an open-mouthed cylindrical shell fitted with a cone-headed piston. A slight clearance between piston and shell, measuring only a few thousandths of an inch, permitted water to pass from one part of the cylinder to another. This "designed leakage" was the key to the valve's self-regulating nature. To unbalance the pressure in the valve, Ensign placed a drain pipe at the rear of the cylinder. When the drain pipe was opened, water flowed out from the rear of the cylinder, reducing the pressure behind the piston, which then slid backward to open the valve. As long as the drain discharged freely, the piston continued to move until the valve was completely open. To maintain the valve at a partially open position, Ensign devised a feed-back mechanism whereby the position of the piston restricted the flow into the drain pipe. When this occurred, the leakage into the rear of the cylinder increased the pressure and restored the equilibrium, bringing the piston to a halt at the desired setting. When the drain pipe was closed completely, leakage continued until full reservoir pressure built up behind the piston, forcing it forward to completely close the valve. By thus regulating the opening and closing of the drain pipe, it was possible to regulate the backward and forward movement of the piston, and the opening and closing of the valve.

Reclamation tested an experimental 20-inch-diameter model of the Ensign valve at Roosevelt Dam in May 1906. On the basis of these tests, Ensign in 1908 designed two 43-inch-diameter valves for the new Roosevelt Dam Powerhouse, for the purpose of regulating the flow of water into the hydroelectric turbines. His invention, however, soon found wider application. In 1909, it became apparent that the outlet gates at both Roosevelt and Pathfinder Dams were functioning so poorly that they endangered the safety of their tunnels. Research would eventually demonstrate that the design was not suitable for pressure heads greater than about 75 feet. As an emergency remedy, Reclamation decided to build new outlets at each dam and equip them with Ensign valves. These were the first of approximately four dozen Ensign valves that Reclamation installed at various dams during the next decade.[5]

Although the Ensign valve allowed Reclamation to proceed with its high-dam construction program, the device was far from perfect. At partial opening under high head, the valve was prone to surface pitting and excessive vibration, accompanied by discharge turbulence and cavitation damage to the outlet tunnels. These were some of the same problems that had plagued the gate-type outlets that the valves were intended to replace. In time, Ensign determined that these conditions were linked to the occurrence of negative pressures below the valves in the outlet tunnels, and that they could be at least partly remedied by introducing air to break up the vacuum and by streamlining the shape of both the valves and the tunnels. The Ensign valve also had a disconcerting tendency to drift from its setting, earning the distrust of dam tenders. Although Ensign eventually redesigned the feedback mechanism to achieve greater control, he never completely solved the problem.[6]

Perhaps the greatest obstacle to improving the Ensign valve was Ensign himself, whose first inclination was to attribute deficiencies in valve performance to the incompetence of manufacturers, installers, and operators. When Frank E. Weymouth, Reclamation's supervising engineer for the construction of Arrowrock Dam, approached Ensign "to discuss with him in a general way the matter of high pressure gates for the Arrowrock Dam," he found that "Mr Ensign would not acknowledge . . . that anything could possibly go wrong with the gate [ie., Ensign valve], if built as designed."

> He would not admit that any one else in the world knew anything about gates and and [sic] appeared to think that it was heresy for any one to even suggest any improvements or changes in his gates. . . . In my talk with him I was unable to get him to discuss details. All of his statements seemed to be of a general tendency that everything in connection with the gate that he did was right and that everything that anybody else did about it was wrong. It is realized, of course, that that line of argument will never help anybody.[7]

Ensign's humor was not improved by the fact that Reclamation had requested an evaluation of his valves from staff engineer F. Teichman, who was attempting to design a competing high-pressure outlet. According to Ensign, the errors in Teichman's design were "so flagrant" and his thinking "so far from the proper assumption of facts" that "after a while I ceased to answer his letters as it appeared to be useless." On his part, Teichman was quite willing to let it be known that the reason why the Ensign valve worked as well as it did was because of an improvement suggested by himself.[8]

Major modification of the Ensign valve did not occur until after Ensign left Reclamation in 1915. Supervision of the needle-valve program passed to Ensign's assistant James M. Gaylord who teamed up with designing engineer John Lucian Savage to undertake a detailed investigation of all Reclamation's high-pressure outlets. Their study revealed that the Ensign valve had two objectionable features. First, the valves and their tunnel outlets continued to experience vacuum-induced cavitation damage. Second, the valves were not readily accessible for repair and maintenance because of their submerged position on the upstream face of the dam. As a solution for both problems, Gaylord in 1918 proposed that future valves be installed on the downstream end of the outlet so that they would discharge directly into the open air. Reclamation's first installation of this type was completed in 1922 at Pathfinder Dam, employing two 58-inch-diameter valves.[9]

To distinguish the new Pathfinder valves, and those patterned after them, from earlier Ensign valves, Reclamation dropped the eponymous designation and referred to the new generation as simply a "balanced needle valve."[10] Operating according to the same hydraulic principles as the original Ensign valve, the Pathfinder valve embodied much the same design, although its downstream location required some structural modification, such as streamlining the needle with a tapered rear casing and placing the resulting device in an elongated shell. The Pathfinder valve also was equipped with a more sensitive feedback mechanism to regulate drainpipe flow, and with a pressurized water inlet line (also known as a "pitot valve") to assist the forward movement of the piston in closing the valve. The entire device was mounted in a valve house which protected the controls from weather.

After successfully testing the new Pathfinder valves, Reclamation abandoned the Ensign valve in favor of the new design. By 1928, the agency had outfitted seven dams with a total of 14 balanced needle valves ranging from 10 to 60 inches in diameter. This deployment reflected an increased confidence by the engineering profession in its ability to build watertight outlet conduits. For example, when Reclamation in 1927 installed balanced needle valves on the downstream face of McKay Dam--an earthfill structure highly sensitive to internal leakage--there was not even a mention of the former taboo against maintaining pressurized water in the body of a dam.[11]

Despite its many years of experience with hydraulically balanced valves, Reclamation found itself under greater constraints in designing the Pathfinder-type valves than the original Ensign valve. This situation was owing to the fact that Reclamation no longer had the field entirely to itself. In 1912, the American inventor Raymond D. Johnson patented a hydraulically balanced, high-pressure needle valve that operated on almost the same principle as the Ensign valve. Having successfully adapted the design to penstock regulation in hydroelectric plants, Johnson in 1918 teamed up with hydraulic engineer Chester W. Larner to found the Larner-Johnson Valve and

Engineering Company, which was responsible for developing, by 1921, a balanced, high-head needle valve for regulating irrigation water discharge at the downstream end of a dam outlet.[12] By 1922, the various Larner-Johnson patents were under the control of the Pelton Water Wheel Company, which had already successfully sued Reclamation for an infringement of Doble's original needle valve design.[13]

Although Reclamation engineers were by no means the first to find their steps dogged by aggressive patent holders, the situation was particularly irksome because some of the patented Larner-Johnson technology had been invented first by Ensign and his staff. But since the designs had neither been put into practice nor patented for the agency's use, they were effectively off limits for government development until the patent expired. As Reclamation's Chief Engineer Walter put it, "the Bureau of Reclamation has been reluctant to . . . [have] trouble with the patentee."[14]

There is no easy explanation for the fact that the Ensign valve was not protected by patent. In 1883, Congress had enacted legislation authorizing federal employees to patent inventions developed during the course of their work, with the proviso that the government retained the right to use the invention free of charge. Basically, this arrangement conformed to the common law of the work place, which granted employers a "shop right" in the inventions of their employees, who otherwise held sole ownership of the patent. Although some federal agencies apparently discouraged workers from seeking patents, Reclamation seems to have supported the intent of the law, at least during Ensign's first years of employment. When in 1906 Reclamation's chief engineer Arthur P. Davis was queried by an employee about the propriety of securing a patent, he replied, "As to the protection of your interest by patent, this seems both natural and right, and, furthermore, is legal, provided that the United States has free use of the invention." By his own account, Ensign filed a patent application for his original valve design shortly after its invention. Unfortunately, he does not mention why the patent was never granted. Since his application preceded that of Johnson by at least two years, his petition was not disqualified by the priority of the other invention.[15]

When Gaylord and Savage began modifying the Ensign valve in the late 'teens, the patent situation for federal employees was considerably less clear. During World War I, the federal government had greatly increased its research activities, becoming an important source of technological innovation. Although existing statutes theoretically protected the patent rights of the federal employee-inventor, the actual execution of those rights became a casualty of war. As a writer in Scientific American noted in 1920, "Widely different views have been held by officials in authority as to the inventor's rights and obligations, and questions of ethics have often arisen. . . . Various restrictions have been placed upon the patenting of inventions evolved in the [government] service, so that an anomalous state, confusing and discouraging to the inventor, has resulted." In an attempt to resolve the confusion, President Harding in 1922 appointed an Interdepartmental Patents Board to investigate past practice and recommend future policy. After two years of study, the board urged all federal agencies to adopt a uniform code that would encourage employees to patent and develop their inventions, unless vital national interests, such as security, clearly dictated otherwise.[16]

Although the various federal departments were unable to agree on a single patent policy, the board's recommendations prodded individual administrations into clarifying their own position. At the Department of the Interior, which included Reclamation, the decision was "to leave the commercial patent rights in inventions with the employee-inventor with the Government retaining a shop right or a license substantially in accordance with the common law." This is effect reaffirmed the validity of the 1883 federal statute.[17]

If there was continuing doubt among Reclamation employees about the propriety of patenting inventions, it was dispelled in January 1928 by Savage, who at that time filed a patent application in his own name for the development of a new method of grouting contraction joints in concrete dams. The resulting patent apparently was the first issued to a Reclamation employee in the post-war period. Since Savage was in charge of Reclamation's research-and-development program, his action was tantamount to an official declaration of policy. Over the next 14 years, Savage and his staff secured patents for at least 23 innovations in hydraulic engineering.[18] Beginning in 1931, virtually all patents were assigned upon issuance to the Universal Hydraulic Corporation of Denver, a firm established by the patentees to handle the private licensing of their inventions. This entrepreneurial arrangement came to an end in November 1942, when the Department of Interior decided that the commercial development of patents by its employees threatened the integrity of the war effort through potential conflicts of interest. Thereafter, employee-inventors were required to assign to the government all rights to any inventions developed within the general scope of their governmental duties.[19]

Whatever the personal financial inducements may have been for the Reclamation engineers, their acquisition of patents made sense from a purely administrative standpoint, for it safeguarded the government's investment in hydraulic technology against the possible claims of private manufacturers. Well aware that the unpatented status of the Ensign valve had been cause for embarrassment, Savage and his colleagues seem to have been particularly assiduous in protecting needle-valve modifications and applications, which accounted for approximately half of the patents issued. This development work gave birth to two important varieties of high-pressure needle valve, each of which enjoyed a brief vogue as a standard, Reclamation, irrigation-discharge outlet for high dams.

The first variety, developed in 1928, was known as the "internal differential needle valve." Like the Ensign valve and the balanced needle valve, this device used reservoir head to increase or decrease water pressure on different parts of a tapered piston, whose resulting movement opened or closed a discharge orifice. It differed from its predecessors, however, in the manner in which the pressure was deployed. While the earlier valves primarily subjected the exterior surfaces of the piston to changes in pressure, the new design created differential pressures inside the piston, equipped for that purpose with internal, inter-connected pressure chambers. By manipulating the flow of pressurized water in, out, and between the chambers, the valve utilized Ensign's original principle of "designed leakage" to achieve self-regulated operation.[20]

The internal-differential concept created a much more compact valve, reducing overall length and weight by as much as 30 percent over the previous balanced needle-valve design. For a 60-inch-diameter valve, the difference represented a savings of approximately 45 inches and 30,000 pounds. Since the cost of a valve was directly proportional to its weight, the new design was considerably more economical to manufacture. Smaller valves also required less floor space for installation and operation, resulting in smaller and cheaper valve houses. Between 1928 and 1935, Reclamation adopted the internal-differential design for a total of 35 valves at six dams, including Deadwood Dam in 1931. Sizes ranged from 48 to 84 inches in diameter.[21]

The search for an even more economical needle valve soon led the Reclamation design staff to modify the traditional action of the valve piston. Ever since the original Ensign valve, the rear of the piston had telescoped inside a guide casing. But in 1936, Reclamation engineers discovered that they could eliminate a good deal of metal work by having the piston slide over, rather than inside, its guide structure. This alteration helped reduce valve weight by about 25 percent. The new design continued to rely on internal-differential pressure chambers. As a means of distinguishing it from its immediate predecessor, it was called the "interior differential needle valve." Reclamation installed a total of 19 interior differential needle valves at 10 dams, with sizes ranging from 36 to 86 inches in diameter. Except for two valves placed at Friant Dam in 1946, all installations took place before World War II.[22]

Although World War II brought new dam construction to a halt, Reclamation engineers continued to work on needle-valve improvements, developing two lighter and smaller varieties known as the "tube valve" and "hollow-jet valve." This work, however, marked the end of the original needle-valve program initiated by Ensign four decades before. The new valve designs were intended for electric-powered, mechanical operation -- a trend that became even more pronounced with Reclamation's development of the jet-flow gate in the mid-1940s. Ensign's goal, however, had been to develop a device that required no external power source, other than the pressure head created by a dam reservoir. Indeed, this was both the strength and weakness of the Ensign valve and its three successors -- the balanced needle, the internal differential needle valve, and the interior differential needle valve.

These designs were highly suitable for the generally remote locations of Reclamation's irrigation storage dams, which, for the most part, had no access to electricity until after World War II. But the success of the valves' hydraulic engineering depended on extremely fine clearances and narrow portings that were difficult to manufacture, and even more troublesome to keep free of water impurities and metallic corrosion. The difficulties of normal maintenance were compounded by the fact that the Reclamation design staff never truly standardized any of the basic valve designs, but kept introducing minor modifications to improve performance. Dam tenders, however, were rarely provided with detailed instruction manuals covering all the idiosyncracies of their particular valve installation. As the Reclamation work force turned over, new engineers and dam tenders alike tended to lose touch with the older valve technology.[23]

Although Reclamation's needle valves were safe when properly maintained and operated, faulty procedures could pose life-threatening hazards. Improper filling or draining of the valve, for example, could introduce air into the pressure chambers without the operator's knowledge. Since air is readily compressed by the enormous pressures utilized in high-head, needle-valve operation, its presence could cause rapid, uncontrollable movement of the valve piston, triggering an explosive rupture of the valve casing. Apparently, it was an operator-error of this type that caused the needle-valve explosion and fatality at Reclamation's Bartlett Dam in 1984. When Reclamation announced its decision the following year to retire all of its active needle valves, an agency spokesperson frankly acknowledged the problems of maintaining an obsolete technology:

> The early century designers of needle valves produced designs that were innovative for the intended purpose of controlling releases from reservoirs in remote locations. The needle valves have proven durable and cost-effective, in terms of the 40 to 70 years of service. Unfortunately, the technical understanding of the design principles of these valves has been lost and has resulted in poor maintenance practices, detrimental modifications, and consequently, misoperation -- placing operating personnel in hazardous situations. If the needle valves were to be retained in service, major overhaul including new materials and modified designs would be required. The estimated cost of accomplishing this effort, plus performing routine annual maintenance, and annual training of operating personnel would be prohibitive. Replacement with a "state-of-the-art" designed regulating gate . . . proves to be more cost-effective.[24]

A complete historical evaluation of Reclamation's needle-valve program requires additional research concerning the valves' distribution and utilization. From the available data, it is clear that during the period 1908 to 1946 Reclamation installed approximately 135 needle valves at about 30 dams. Used primarily for regulating irrigation discharge, these outlets served virtually every storage dam over 100 feet in height built by Reclamation between the two world wars. It is not known, however, how frequently, or under what circumstances, other dam-building agencies used the various Reclamation designs. Neither Reclamation nor the contemporary engineering press compiled statistics on the subject. Although it is probable that the Reclamation patentees themselves kept track of their licensing agreements, their papers apparently have not survived.

But even a precise accounting of all valves based on Reclamation designs would tell only part of the story of the agency's influence on the development of hydraulic outlet technology. During the early twentieth century, Ensign and his staff were the first to demonstrate the feasibility of employing hydraulically balanced needle valves for high-pressure, irrigation-discharge regulation. Their work encouraged others to enter the field, most notably the Larner-Johnson Valve and Engineering Company, which closely patterned its first high-pressure irrigation outlets after Reclamation's unpatented technology. Although the Larner-Johnson irrigation outlet never significantly advanced beyond Reclamation's unpatented, balanced needle valve of the 1920s, it found world-wide acceptance as a dependable, readily-available, stock mechanism for high-pressure discharge. In 1929, for example, the journal of the American Society of Mechanical Engineers Transactions noted that the Larner-Johnson valve was "becoming the accepted standard" for commercial high-pressure, discharge regulators--an observation that simultaneously paid tribute to American private enterprise and government engineering.[25]

APPENDIX ENDNOTES

1. The definition of a needle valve is from Bureau of Reclamation, "Design Standards 1950," Section 1.4, mimeographed publication in Technical Library, Denver. On Doble, see Norman Smith, Man and Water (Charles Scribner's Sons, 1975), 184-185. Although Doble patented several designs based on the same needle-valve principle, the original invention was covered by Patent No. 660,789, granted October 30, 1900, on an application filed October 17, 1899.

2. For a brief discussion of control gates prior to the Reclamation era, see D. W. Cole, "High-Pressure Gates in Dams for Water-Works and Irrigation Reviewed," Engineering News-Record 81 (November 14, 1918): 880-881. A senior engineer with Reclamation, Cole is worth quoting at some length:

> "One of the most difficult problems encountered by the Reclamation Service in all its work has been the development of efficient and safe high-pressure gates with their operating mechanisms. The entire problem was precipitated suddenly in the beginning when it was realized that relatively much greater quantities of water were required for irrigation, and must be regulated through larger outlets from deeper reservoirs, than had ever been attempted. Illustrating this point, it may be noted that the largest city water-supply conduit in the world, the new Catskill Aqueduct for New York City, with a daily capacity of 500,000,00 gal[lons] . . . has only about one-third the water-carrying capacity of one of the large Reclamation Service project main canals, such as the Boise Canal. In order to get the water out of deep reservoirs in the lavish quantity required for irrigation it devolved upon the Reclamation Service to devise large-capacity gates, which may be operated under 200-ft. heads, or practically four times the head commonly dealt with in the largest municipal storage reservoirs."

3. For biographical sketches of Ensign, see "Our Engineers," Reclamation Record 6 (January 1915): 28; "Orville Hiram Ensign, 1863-1935," Reclamation Era 25 (August 1935): 159; Who Was Who in America (Chicago: The A. N. Marquis Company, 1942), 374. Ensign's invention (and its assignment to Doble) is covered by Patent No. 752,539, granted February 16, 1904, on an application filed November 13, 1903. Reclamation was interested in developing hydroelectricity at its dams primarily as a source of "cheap power for raising underground water to the surface or surface waters to lands which are too high to be reached by the ordinary gravity method [of irrigation]"; F. H. Newell, "Electrical Features of the U.S. Reclamation Service," American Institute of Electrical Engineers Proceedings 33 (October 12, 1914): 1584. See also O. H. Ensign and James M. Gaylord, "Electric Power for Irrigation," Engineering News 66 (July 6 1911): 4-9.

4. On the development of the Ensign valve, see J. M. Gaylord and J. L. Savage, High-Pressure Reservoir Outlets (Washington, D.C.: Government Printing Office, 1923), 3-7; 64-65. Ensign discussed the background planning for his "gate" in a letter to Reclamation's chief engineer, F.H. Newell, dated April 9, 1906, in Bureau of Reclamation, General Correspondence, File No. 910-12, Box 290, Entry 3, Record Group 115, National Archives, Washington, D.C (hereafter this collection will be cited as RG-115, NARA; this letter, as well as other valuable needle-valve material in the same collection, was called to the author's attention by historian Fredric L. Quivik). The standard engineering thinking on outlet gates is contained in Newell's Principles of Irrigation Engineering (New York: McGraw-Hill Book Company, 1913), 250: "The gates which control the outlet of a reservoir should be so located that when closed they exclude water from entering the conduit or channel through which water is to be discharged. This is usually accomplished by locating the gates at the upper end . . . . If the gates are placed far back in the body of the dam, the water standing against them when closed exerts the full pressure of the reservoir head on the walls of the conduit and may find entrance into the dam itself by percolation through these walls." Before publishing his text, Newell had asked Ensign to review the section on outlets. Although Ensign marked up a number of paragraphs, he approved the above passage without comment; see Ensign to Newell, "Subject: Outlet Works," June 25, 1912, File No. 910, Box 285, Entry 3, RG-115, NARA.

5. Gaylord and Savage, High-Pressure Reservoir Outlets, 48, provides a list of Ensign valve installations, described in detail in the remainder of the book; for Roosevelt and Pathfinder Dams, see 49-62, 77-96. Ensign reported on the testing of his first experimental valve in a letter to Newell, dated May 24, 1906, File No. 910-12, Box 290, Entry 3, RG-115, NARA.

6. On the formation of vacuum and its remedies, see Gaylord and Savage, High-Pressure Reservoir Outlets, 8-9. The same authors also discuss operating problems of the Ensign valve, 40-44, 56-60, 70-71, 88-90, 99-101; see also A. P. Davis to Ensign, November 19, 1912; Davis to F. E. Weymouth, December 14, 1912; Davis to D. C. Henny, December 14, 1912, all in File No. 910-12, Box 290, Entry 3, RG-115, NARA.

7. "I might add that I feel very badly over the ill luck that has been had with the balanced valves to date, yet I do not believe I could attach any great blame to myself . . ."; Ensign to A. P. Davis, September 24, 1912. In less defensive moments, when Ensign was willing to discuss design problems in his invention, he noted with justice that his work had suffered from "the lack of empirical data for design." As he wrote to Davis on December 3, 1912, "please bear in mind that at Roosevelt, Belle Fourche and Pathfinder the installation of these valves was to remedy difficulties which had arisen with other methods of controlling the discharge, and these installations were not designed to fit the new method but to modify the old one, and in each of these cases the work was done under some considerable pressure of speed to meet what might be called an emergency, without a chance to thoroughly develop an

apparatus designed to solve a problem unique in itself and of considerable magnitude, without any precedent whatever of similar magnitude." For Weymouth's comments, see Weymouth to A. P. Davis, December 10, 1912, On the general need for "delicacy" and "tact" in dealing with Ensign, see A. P. Davis to D.C. Henny, December 14, 1912. All of the foregoing correspondence is in File No. 910-12, Box 290, Entry 3, G-115, NARA.

8. Reclamation chief A.P. Davis asked Teichman to study the Ensign valve in a letter dated November 19, 1912. Ensign lambasted Teichman's work in a letter to Davis, dated September 24, 1912; see also Ensign's acidly polite letter to Teichman, dated December 18, 1912 ("There are one or two points to which I wish to call your attention . . ."; "You may have forgotten, but . . ."; I should call your attention to one peculiar phenomena of this valve which you no doubt have discovered in your calculations . . . . ") All the foregoing correspondence is in File No. 910-12, Box 290, Entry 3, RG-115, NARA. Teichman retaliated in print by claiming that the improved control mechanism for the Ensign valve, which made it a more workable device, was "first suggested by the writer"; see Teichman, "Slide Gates and Needle Valves in the Elephant Butte Dam," Engineering News 77 (February 22, 1917): 308.

9. Gaylord and Savage, High-Pressure Reservoir Outlets, 82-83. Gaylord and Savage requested approval for their study in a "Memorandum to the Chief of Construction," dated February 12, 1918; see also F.E. Weymouth to A.P. Davis, February 13, 1913, File No. 910-12, Box 291, Entry 3, RG-115, NARA.

10. The new terminology appears in C.M. Day, "High-Pressure Reservoir Outlets," Dams and Control Works: A Description of Representative Storage and Diversion Dams and High-Pressure Reservoir Outlet Works Constructed by the Bureau of Reclamation (Washington, D.C: Government Printing Office, 1929), 92-104.

11. The design of the Pathfinder valve is discussed in Gaylord and Savage, High-Pressure Reservoir Outlets, 83-85. The statistics on valve installation are from "McKay Dam Needle Valve Investigation Report," unpublished, November 1986, p. 4, in Bureau of Reclamation Engineering and Research Center, Denver. For contemporary discussion of the McKay Dam outlets, see Day, "High-Pressure Reservoir Outlets," 97, 100. Of the seven dams receiving balanced needle valves, three were existing facilities that required new outlets. These were Pathfinder in Wyoming, Lahontan in Nevada, and Shoshone (later renamed Buffalo Bill), also in Wyoming. Plans for the Pathfinder valves were drawn up in 1919, but interruptions in funding delayed final installation until 1922. The Shoshone and Lahontan outlets were modified in 1921 and 1924 respectively. The other four facilities were completely new construction, as follows: Hubbart Dam in Nevada (1924), Tieton Dam in Washington (1925), McKay Dam in Oregon (1927), Stony Gorge Dam in California (1928). With the exception of Hubbart Dam, which Reclamation designed for the Bureau of Indian Affairs, all of the above structures were built and operated by Reclamation.

12. The original Johnson needle valve design is covered by Patent No. 1,030,890, filed October 8, 1909, approved July 2, 1912. As Gaylord and Savage acknowledged (High-Pressure Reservoir Outlets, 7), Johnson's invention was "more or less independent of the work of the Bureau of Reclamation." The Johnson design was first applied to hydroelectric penstock regulation in 1911, by the Ontario Power Company in Niagara Falls, New York, where Johnson worked as a hydraulic engineer. An English description of the Niagara Falls installation credits the valve's invention to Jens Orten-Boving, a Swedish national living in London. Although Orten-Boving patented two other hydraulic devices in the United States during this period (see Patent Nos. 993,616 and 1,007,230), he is not mentioned in the patent granted to Johnson for the needle valve. But the Swedish inventor apparently had something to do with the valve's development, since, as late as 1922, the device was described in the English engineering press as "the Johnson-Boving Valve." After Johnson's association with Larner, the term "Larner-Johnson valve" gained currency. On these matters, see "A New Hydraulic Valve," The Engineer (London) 111 (March 24, 1911): 297; "Salmon River Hydroelectric Development," Engineering Record 69 (June 13, 1914): 672, 674; "The Johnson-Boving Valve," Engineering (London) 113 (January 6, 1922), 24; Ross L. Mahon, "Hydraulic Butterfly Valves," American Society of Mechanical Engineers Transactions 54 (May 15, 1932): 17; Lawrence H. Burpee, "Erection of a Large Johnson Valve," Canadian Engineer 52 (June 21, 1927): 606. On Larner's collaboration with Johnson in the formation of the Larner-Johnson Valve and Engineering Company in 1918, see "Chester Larner, Engineer, 61, Dead," New York Times, June 14, 1942, 46:5. The company brought out its first catalog, Bulletin No. 1," in July 1918. Bulletin No. 2, published in January 1921, devotes several pages to Larner-Johnson's new "regulator for dam outlets," which was designed for installation on the downstream end of the outlet. Reclamation kept abreast of Larner-Johnson developments, as is evidenced by the fact that the bulletins in the agency's possession bear the name of "C. M. Day," a mechanical engineer who was involved with Reclamation's needle valve program during the 1920s. Copies of the Larner-Johnson bulletins were made available to the author by Jim Wadge, Mechanical Engineer, Bureau of Reclamation Engineering and Research Center, Denver.

13. Pelton Water Wheel Company gained access to Larner-Johnson technology as part of a holding-company pyramid that placed both Pelton and Larner-Johnson under the control of William Cramp and Sons Ship and Engine Building Company of Philadelphia. In 1917, Cramp had bought I.P Morris Company, which acquired control of Pelton in 1922. Cramp also seems to have had a controlling interest in Larner-Johnson, although the precise relationship has not been determined. In 1920, Cramp's vice-president Harvey B. Taylor is listed as co-owner of an important Larner-Johnson patent, and in 1921, Cramp is described as the "American manufacturers of the Johnson valve"; see Patent No. 1,356,238, filed March 6, 1919; approved October 19, 1920; Larner-Johnson Valve and Engineering Company, "Bulletin No. 2"; Moody's Analysis of Investments and Security Rating Service . . . 1925 (New York: Moody's Investors Service, 1925), p. 1846. After I. P. Morris's acquisition of Pelton

in 1922, the Larner-Johnson catalog (now published by I. P. Morris) names Pelton as the West Coast manufacturer of the valves, noting that "the same products, character of engineering and manufacturing facilities are available in associate companies with complete inter-company co-operation"; see I. P. Morris Corporation, "Larner-Johnson Valves, Bulletin No. 8," September 1927. Pelton's patent litigation against Reclamation is noted in Gaylord and Savage, High-Pressure Reservoir Outlets, 55.

14. Walter to [C. L. Tice,] Reservoir Superintendent, McKay Dam, March 3, 1927, Box 1379. Walter's comment is specifically in reference to a feed-back control mechanism "first applied to the Ensign type of balanced valve in about 1907" but subsequently covered by a Larner-Johnson patent.

15. For the patent rights of federal employees during the period 1883 to 1923 (and the acknowledgement that "misunderstandings and embarrassment have continually arisen with regard to them"), see U.S. Congress, Senate, Report of the Interdepartmental Patents Board, S. Doc. 83, 68th Cong., 1st sess. 1924, 1-4. Davis' comment on patents is particularly germane since the invention in question was a high-pressure gate intended as a possible alternative to the Ensign valve; see A. P. Davis to D. W. Ross, July 7, 1906, File No. 910-12, Box 290, Entry 3, RG-115, NARA. Ensign's reference to his patent application is found in Ensign to Davis, January 8, 1913, File No. 910-12, Box 291, Entry 3, RG-115, NARA.

16. Andrew Stewart, "Creating an Asset," Scientific American 122 (April 10, 1920): 394; U.S. Senate, Report of the Interdepartmental Patents Board, 4-7.

17. U.S. Congress, Senate, Subcommittee on Patents, Trademarks, and Copyrights of the Committee on the Judiciary, Patent Practices of the Department of the Interior (Washington, D.C.: U.S. Government Printing Office, 1962), p. 6.

18. Listed chronologically by date of application, the 23 patents are as follows:

> John L. Savage, "Method and Apparatus for Grouting Concrete Structures," Patent No. 1,726,414, filed January 16, 1928, approved August 27, 1929; Leslie N. McClellan and others, "Pressure Actuated Control Valve," Patent No. 1,750,417, filed January 31, 1928, approved March 11, 1930; Phillip A. Kinzie and John L. Savage, "Fluid Handling and Controlling Apparatus," Patent No. 1,840,205, filed August 11, 1928, approved January 5, 1932; Phillip A. Kinzie and John L. Savage, "Fluid Flow Control Apparatus," Patent No. 1,878,150, filed August 11, 1928; approved September 20, 1932; Leslie N. McClellan and others, "Pressure-Relief Valve," Patent No. 1,795,662, filed January 18, 1929, approved March 10, 1931; Leslie N. McClellan and others, "Combined Flow Control and Check Valve," Patent No. 1,856,222, filed January 18, 1929, approved May 3, 1932; Phillip A. Kinzie, "Valve Control Mechanism," Patent No.

2,045,232, filed February 8, 1930 (renewed May 15, 1935), approved June 23, 1936; Phillip A. Kinzie, "Hydro-Mechanically Controlled Needle Valve," Patent No. 1,919,112, filed June 18, 1930, approved July 18, 1933; Phillip A. Kinzie, "Pressure Actuated Valve," Patent No. 1,980,067, filed June 16, 1931, approved November 6, 1934; Phillip A. Kinzie, "Valve," Patent No. 1,919,165, filed August 22, 1931, approved July 18, 1933; Phillip A. Kinzie, "Valve," Patent No. 2,054,258, filed May 7, 1932, approved September 15, 1936; Phillip A. Kinzie, "Needle Valve," Patent No. 1,998,459, filed December 28, 1932, approved April 23, 1935; Phillip A. Kinzie, "Valve," Patent No. 1,998,458, filed December 28, 1932, approved April 23, 1935; Phillip A. Kinzie, "Reciprocating Gate Valve," Patent No. 2,131,050, filed February 8, 1933 (renewed October 22, 1937), approved September 27, 1938; Phillip A. Kinzie, "Torque Mechanism," Patent No. 2,059,366, filed June 11, 1935, approved November 3, 1936; Phillip A. Kinzie and others, "Internal Stem Operated Tractor Gate," Patent No. 2,131,051, filed December 28,1935, approved September 27, 1938; Phillip A. Kinzie and others, "Cable Operated Tractor Gate," Patent No. 2,131,052, filed December 28, 1935, approved September 27, 1938; Phillip A. Kinzie and Grover J. Hornsby, "Interior Differential Needle Valve," Patent No. 2,191,532, filed March 3, 1936, approved February 27, 1940; Phillip A. Kinzie and Warren H. Kohler, "Gate Valve," Patent No. 2,131,053, filed October 10, 1936, approved September 27, 1938; Phillip A. Kinzie and John L. Savage, "Tube Valve," Patent No. 2,265,435, filed February 11, 1938, approved December 9, 1941; Phillip A. Kinzie, "Pressure-Sealed Valve," Patent No. 2,265,176, filed April 22, 1938, approved December 9, 1941; Phillip A. Kinzie, "Valve," Patent No. 2,187,787, filed May 24, 1938, approved January 23, 1940; Phillip A. Kinzie, "Tube Valve," Patent No. 2,269,671, filed May 31, 1939, approved January 13, 1942.

19. On the new patent policy, and its continuance into the post-war years, see Patent Practices of the Department of the Interior, 6. The corporate structure of the Universal Hydraulic Corporation is something of a mystery. The firm is listed as the assignee of at least 20 patents issued to Reclamation employees between March 10, 1931 and December 9, 1941. These documents declare that the company is "a corporation of Colorado." However, the Colorado Secretary of State's Office has no record that any corporation by such name was ever legally organized in the state. Nor do Denver phone directories and city directories give any listing for the company. All of the patentees are deceased, except for Warren H. Kohler who began work for Reclamation as a draftsman in 1930 and retired more than three decades later as Head of the Large Gates and Valves Section. Kohler confirms that Savage and other senior engineering staff organized a company to license their inventions, but says he was not privy to the exact arrangements; author's interview with Kohler, October 16, 1990.

20. The original internal-differential design was covered by Patent No. 1,750,417 issued March 11, 1930 to Leslie N. McClellan and others on an application filed January 31, 1928. Unless, otherwise noted, the description of the internal differential valve, as well as the ensuing discussion of subsequent Reclamation valve technology, is based on the following sources, listed in order of increasing technical detail: Bernard A. Halliday and Carl J. Hoffman, "Types of Gates, Valves, and Control Equipment Used for Bureau of Reclamation Spillways and Outlets," International Congress on Large Dams, Fourth Congress, Transactions (1951): 169-194; G.J. Hornsby, "Developments in Regulating Outlet Valves," American Society of Mechanical Engineers Transactions 64 (February 1942): 85-90; Arthur W. Tschannen, "Reservoir Outlets and Spillway Gates," in United States Department of the Interior, Bureau of Reclamation, Dams and Control Works (Washington, D.C. Government Printing Office, 1953, 3d. ed.), 205-218; Warren H. Kohler and James W. Ball, "High-Pressure Outlets, Gates, and Valves," in Handbook of Applied Hydraulics, eds., Calvin Victor Davis and Kenneth E. Sorensen (New York: McGraw-Hill Book Company, 1969, 3d. ed), Section 22, 1-31; P. A. Kinzie, "High-Pressure Reservoir Outlets," in Dams and Control Works (1938, 2d ed.), 177-204.

21. On the crucial relationship between valve weight and cost, see Bureau of Reclamation, "Design Standards No. 7," (1950), Sec. 1.1. The example of the new design's economy is drawn from the original patent application; see Patent No. 1,750,417. The statistics on valve installation are from "McKay Dam Needle Valve Investigation Report," 4. The six dams are as follows: Echo Dam in Utah (1928), Gibson Dam in Montana (1928), Coolidge Dam in Arizona (1928), Deadwood Dam in Idaho (1931), Owyhee Dam in Oregon (1932), and Hoover Dam in Nevada (1935). With the exception of Coolidge Dam, which Reclamation designed for the Bureau of Indian Affairs, all of the above structures were built and operated by Reclamation.

22. The original interior-differential design was covered by Patent No. 2,191,523 issued to Phillip A. Kinzie and Grover J. Hornsby February 27, 1940, on an application filed March 3, 1936. The statistics on valve installations are from "McKay Dam Needle Valve Investigation Report," 4-5. The ten dams, all built and operated by Reclamation, are as follows: Moon Lake Dam in Utah (1936), Taylor Park Dam in Colorado (1936), Agency Valley Dam in Oregon (1936), Seminoe Dam in Wyoming (1936), Alcova Dam in Wyoming (1936), Bartlett Dam in Arizona (1937), Sumner Dam in New Mexico (1937), Grassy Lake Dam in Wyoming (1937), Boca Dam in California (1937), and Friant Dam in California (1946). Almost all internal and interior differential valves were governed by an externally-mounted, self-regulating, multi-ported control device that regulated the flow of water in the pressure chambers; see Phillip A. Kinzie, "Valve Control Mechanism," Patent No. 2,045,232, filed February 8, 1930, approved June 23, 1936. Because the device moved the valve in a manner that appeared to contradict its own motion, it was commonly called a "paradox control." In lighter moments, the Reclamation engineering staff affirmed that its name derived from the device's complicated engineering, which "looked like it would never work, but somehow did"; author's interview with Kohler.

23. Vern, Yocum, "Investigation of Outlet Works Needle Valves," in U.S. Bureau of Reclamation, Water Operation and Maintenance Bulletin No. 144 (June 1988): 18-19.

24. Ibid, 17.

25. "The Johnson Hydraulic Valve and Differential Surge Tank," Larner-Johnson Valve and Engineering Company Bulletin No. 2 (January 1921): 23-33; "Larner-Johnson Valves," I.P. Morris Corporation Bulletin No. 8 (September 1927): 9-11. For examples of Larner-Johnson free-discharge valve installations in the United States, Italy, and Mexico, see, respectively: "The Hetch-Hetchy Water Supply of the City of San Francisco," Engineering 122 (July 23, 1926): 94-97; "Free Discharge," Water and Water Engineering (Supplement Section) 39 (September 1937): 20-21; Augustin M. Valdes, "A Modern Mexican Irrigation Development," Civil Engineering 1 (August 1931): 1009-1014. The concluding quotation is from "Progress in Hydraulics," American Society of Mechanical Engineers Transactions HYD-50-1 (1929): 4; see also "Progress in Hydraulics," American Society of Mechanical Engineers Transactions 48 (December 1926): 1419.

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